

22-2173

**IN THE UNITED STATES COURT OF APPEALS  
FOR THE FEDERAL CIRCUIT**

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PARKERVISION, INC.,

Appellant,

v.

INTEL CORPORATION,

Appellee.

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On Appeal from the Patent Trial and Appeal Board  
Proceeding No. IPR2021-00346

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**BRIEF OF APPELLANT PARKERVISION, INC.**

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January 17, 2023

**PATENT CLAIMS AT ISSUE**

**U.S. PATENT NO. 8,190,108 B2, CLAIM 1:**

1. A frequency conversion module, comprising:  
a first switch configured to up-convert a signal based on a control signal and  
a bias signal,  
wherein said signal are routed to said frequency conversion module via a  
second switch, and  
wherein said signal is transmitted by an antenna connected to a third switch.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 6:**

6. The frequency conversion module of claim 1, further comprising:  
a pulse shaper; and  
an oscillating signal generator.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 7:**

7. The frequency conversion module of claim 6, wherein the oscillating signal generator comprises a voltage controlled oscillator configured to generate an oscillating signal.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 8:**

8. The frequency conversion module of claim 7, wherein the pulse shaper is configured to generate a string of pulses based on the oscillating signal.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 9:**

9. The frequency conversion module of claim 8, wherein the first switch opens and closes based on the string of pulses.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 12:**

12. A method for frequency conversion, comprising:

up-converting a signal based on a control signal and a bias signal using a frequency conversion module,

wherein the signal is routed to an antenna via a first switch,

wherein the signal is routed to the frequency conversion module via a second switch, and

wherein the frequency conversion module comprises a third switch and is configured to up-convert the signal using the third switch.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 17:**

17. The frequency converter of claim 12, wherein the frequency conversion module comprises a pulse shaper and an oscillating signal generator.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 18:**

18. The frequency converter of claim 17, wherein the oscillating signal generator comprises a voltage controlled oscillator configured to generate an oscillating signal.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 19:**

19. The frequency converter of claim 18, wherein the pulse shaper is configured to generate a string of pulses based on the oscillating signal.

**U.S. PATENT NO. 8,190,108 B2, CLAIM 20:**

20. The frequency converter of claim 19, wherein the third switch opens and closes based on the string of pulses.

FORM 9. Certificate of Interest

Form 9 (p. 1)  
July 2020

**UNITED STATES COURT OF APPEALS  
FOR THE FEDERAL CIRCUIT**

**CERTIFICATE OF INTEREST**

**Case Number** 22-2173

**Short Case Caption** ParkerVision, Inc. v. Intel Corporation

**Filing Party/Entity** ParkerVision, Inc.

**Instructions:** Complete each section of the form. In answering items 2 and 3, be specific as to which represented entities the answers apply; lack of specificity may result in non-compliance. **Please enter only one item per box; attach additional pages as needed and check the relevant box.** Counsel must immediately file an amended Certificate of Interest if information changes. Fed. Cir. R. 47.4(b).

I certify the following information and any attached sheets are accurate and complete to the best of my knowledge.

Date: 01/17/2023

Signature: /s/ Ronald M. Daignault

Name: Ronald M. Daignault

## FORM 9. Certificate of Interest

Form 9 (p. 2)  
July 2020

<b>1. Represented Entities.</b> Fed. Cir. R. 47.4(a)(1).	<b>2. Real Party in Interest.</b> Fed. Cir. R. 47.4(a)(2).	<b>3. Parent Corporations and Stockholders.</b> Fed. Cir. R. 47.4(a)(3).
Provide the full names of all entities represented by undersigned counsel in this case.	Provide the full names of all real parties in interest for the entities. Do not list the real parties if they are the same as the entities.  <input checked="" type="checkbox"/> None/Not Applicable	Provide the full names of all parent corporations for the entities and all publicly held companies that own 10% or more stock in the entities.  <input checked="" type="checkbox"/> None/Not Applicable
ParkerVision, Inc.	None	None

☐ Additional pages attached

## FORM 9. Certificate of Interest

Form 9 (p. 3)  
July 2020

**4. Legal Representatives.** List all law firms, partners, and associates that (a) appeared for the entities in the originating court or agency or (b) are expected to appear in this court for the entities. Do not include those who have already entered an appearance in this court. Fed. Cir. R. 47.4(a)(4).

☐ None/Not Applicable

☐ Additional pages attached

Daignault Iyer LLP: Stephanie Mandir		

**5. Related Cases.** Provide the case titles and numbers of any case known to be pending in this court or any other court or agency that will directly affect or be directly affected by this court's decision in the pending appeal. Do not include the originating case number(s) for this case. Fed. Cir. R. 47.4(a)(5). See also Fed. Cir. R. 47.5(b).

☐ None/Not Applicable

☐ Additional pages attached

ParkerVision v. Intel Corp. WDTX-6:20-cv-00562		

**6. Organizational Victims and Bankruptcy Cases.** Provide any information required under Fed. R. App. P. 26.1(b) (organizational victims in criminal cases) and 26.1(c) (bankruptcy case debtors and trustees). Fed. Cir. R. 47.4(a)(6).

☒ None/Not Applicable

☐ Additional pages attached


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**STATEMENT OF RELATED CASES**

No appeal in or from the same proceedings in the United States Patent and Trademark Office Patent Trial and Appeal Board (“PTAB” or “Board”) was previously before this Court or any other appellate court. ParkerVision, Inc. (“ParkerVision” or “Appellant”) has asserted U.S. Patent No. 8,190,108 (“the ’108 patent”) in the following district court case: *ParkerVision, Inc. v. Intel Corp.*, Case No. 6:20-cv-00562-ADA (W.D. Tex.).

### **JURISDICTIONAL STATEMENT**

The PTAB had jurisdiction over the petition for *inter partes* review (“Petition”) brought by Intel Corporation (“Intel”) under 35 U.S.C. § 6 that is the subject of this appeal: IPR2021-00346. The PTAB issued its Final Written Decision in IPR2021-00346 on June 30, 2022. Appx1-73. Appellant ParkerVision timely filed a notice of appeal on August 29, 2022. Appx74-78. This Court has jurisdiction under 35 U.S.C. § 141(c) and 319 and 28 U.S.C. § 1295(a)(4)(A).

### **STATEMENT OF THE ISSUES**

1. Whether the PTAB erred by invalidating the challenged claims based on an incorrect claim construction of “switch,” where the PTAB failed to consider the complete disclosure of the patent specification and gave no deference to the prior claim constructions of two District Courts.
2. Whether, based on impermissible hindsight, the PTAB erred by finding that a POSITA would have been motivated to replace an amplifier circuit of Downey with a switch circuit from Sedra, thereby abandoning the express teachings of Downey, changing the basic principle of operation in Downey, and rendering Downey inoperable for its intended purpose.
3. Whether the PTAB erred by finding the prior art combination disclosed the required claim limitation “first switch configured to up-convert a signal,” in the

absence of substantial (or any evidence) that the combined references disclosed a “switch.”

4. Whether the PTAB erred when it based its unpatentability decision on new theories not presented in the Petition but, instead, theories that were raised for the first time in Intel’s Reply.

### **STATEMENT OF THE CASE**

This case is an appeal of the PTAB’s Final Written Decision (“FWD”) in IPR2021-00346, which challenged claims 1, 6-9, and 17-20 of the ’108 patent.

#### **I. OVERVIEW OF WIRELESS TECHNOLOGY**

The ’108 patent relates to wireless communication and, more particularly, to frequency up-conversion of electromagnetic (EM) signals. Appx2337; Appx2564(¶ 22).

##### **A. Wired communications.**

Traditional wired communications networks transmit audio signals over wire lines by converting audio signals to electrical signals and back to audio signals. Appx2337; Appx2565(¶ 23).



When Bob speaks into a phone, Bob's phone converts his voice (low frequency audio signals) into electrical signals. Electrical signals are transmitted over wires to Alice's phone, which converts the electrical signals back into audio signals so that Alice can hear Bob's voice. Appx2338; Appx2565(¶ 24).

**B. Wireless Communications.**

Similar to wired communications, in wireless communications, low frequency audio signals are converted into electrical signals. But instead of travelling through wires, the signals are transmitted through air as radio waves (electromagnetic (EM) waves). Appx2338; Appx2565(¶ 25).



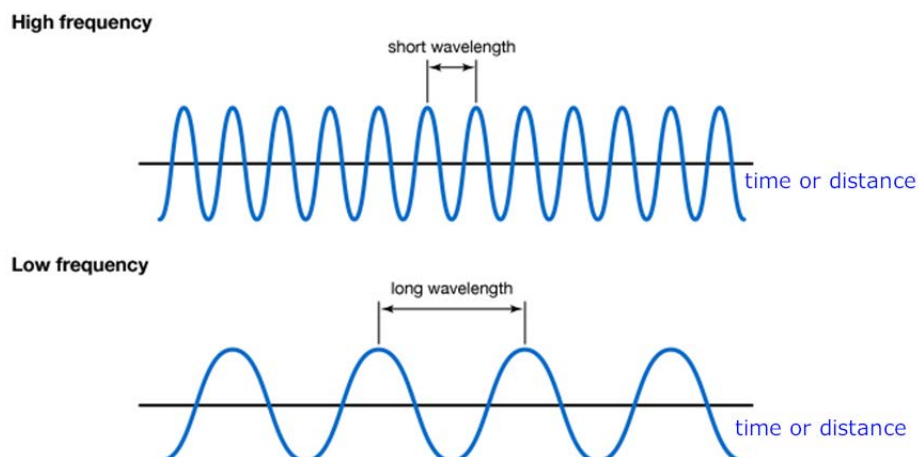
As shown above, wireless devices use high radio frequency (RF) signals (e.g., above 300 MHz (red)) because high frequency signals can carry more information and because high frequency antennas can physically fit within small devices such as cellular phones. Appx2338-2339; Appx2566(¶ 26).



In a wireless communication, when Bob speaks into his cell phone, Bob's cell phone converts his voice (low frequency audio signals) into a high frequency RF signal. The RF signal is transmitted over the air to Alice's cell phone. Alice's cell phone then converts the RF signal back into a low frequency audio signal and Alice can hear Bob's voice. Appx2339; Appx2566(¶ 27).

### C. Frequency.

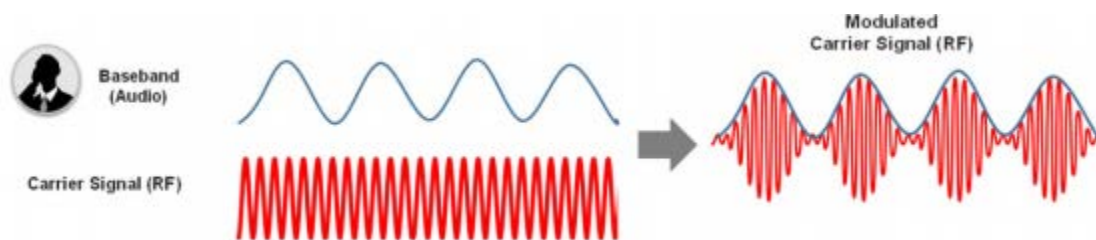
Frequency is the number of cycles of a wave per unit time (second). Appx2339; Appx2567(¶ 28).



As shown above, a high frequency signal has more cycles of a wave per second than a low frequency signal. Notably, the frequency of an audio wave can be one thousand cycles per second whereas the frequency of a radio wave can be one billion cycles per second. Appx2340; Appx2567(¶ 29).

#### **D. Up-conversion.**

In order to transmit an audio signal over air, a wireless device must transform the audio signal to an RF signal. Since the RF signal is used to carry the information in the audio signal, the RF signal is referred to as a “carrier signal.” And since audio waves are at a low frequency, they are referred to as “baseband,” a “baseband signal” or at a “baseband frequency.” Appx2340; Appx2567(¶ 30).



In order to transport the baseband (audio) signal, the transmitting wireless device (e.g., Bob’s cell phone) modifies the carrier (RF) signal. As shown above, the baseband signal is impressed upon the carrier signal (above left), thereby modulating/changing the shape of the carrier signal to approximate the shape of the

baseband (audio) signal (above right).<sup>1</sup> The modified signal is referred to as a “modulated carrier signal.” The process is referred to as “up-conversion” because the low frequency signal is being up-converted to a high frequency signal. Up-conversion is the subject of claims 1, 6-9, 12, and 17-20 of the ’108 patent.<sup>2</sup> Appx2340-2341; Appx2568(¶ 31).

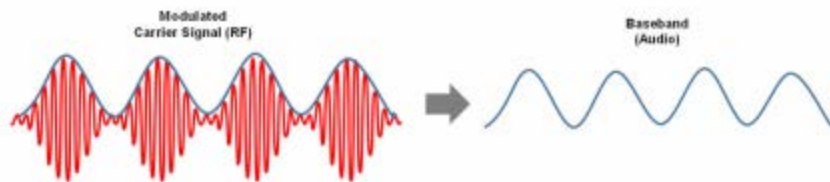
**E. Down-conversion.**

In order for the receiving wireless device (e.g., Alice’s cell phone) to recover the baseband (audio) signal from the modulated carrier signal, the receiving wireless device must transform the modulated carrier signal back to an audio signal. This process is referred to as “down-conversion” because a high frequency signal is being down-converted to a low frequency signal. Appx2341; Appx2568-2569(¶ 32).

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<sup>1</sup> This type of modification is referred to as amplitude modulation. But other types of modulation can be used, which involve modifying other properties of the carrier signal, such as frequency or phase.

<sup>2</sup> While Section I provides an overview of the technology in connection with voice/audio signals, it should be understood that this is for illustrative purposes only.



As shown above, “down-conversion” is the process by which the baseband (audio) signal can be recovered from the carrier signal. Appx2342; Appx2569(¶ 32).

## II. IMPORTANT CONCEPTS RELATED TO WIRELESS TECHNOLOGY

### A. Basic circuit concepts.

RF signals are created using electronic circuits. To understand circuits, it is important to understand the concepts of charge, voltage, current, energy, power, resistance and impedance. Appx2342; Appx2571(¶ 38).

Charge: In a circuit, there are two physical types of charge – positive charge and negative charge. Protons have a positive charge (+) and electrons have a negative charge (–). Appx2342; Appx2572(¶ 39).

Circuits operate based on the movement of electrons and the movement of charge transfers energy. Charge may build up to establish a voltage signal. Here, a voltage signal refers to information that is almost entirely conveyed as a voltage. Alternatively, the movement of charge, the rate of which is current, may itself be

the signal. Most circuits convey information, i.e., present signals, as a voltage or as a current. Appx2342; Appx2572-2573(¶¶39-42).

Voltage: Voltage is the difference in an electron's potential energy, per unit charge, between two points. In other words, voltage is the amount of potential (electrical) energy available, per unit charge. Negative charges (electrons) are pulled towards higher voltages, while positive charges (protons) are pulled towards lower voltages. Appx2343; Appx2573(¶ 43).

Electric current: An electric current is the movement/flow of charge in a circuit (in a conductor or into, out of, or through an electrical component). Current (the net rate of movement of positive charges) flows from positive voltage to negative voltage. Appx2343; Appx2573(¶ 44).

Electric energy: Electric energy is energy that results from the movement of a charge in a circuit. The faster the charges move and the more charges that move, the more energy they carry. The only way to transfer energy is by transferring charge. So, movement of a charge indicates movement of energy.

Energy is not the same as voltage. Energy and voltage are used in circuits in *different ways*. Appx2343; Appx2574-2575(¶¶ 45-49).

Power: Power is the amount of energy transferred per unit time. Power is the average rate at which energy is transferred by charges. Appx2343; Appx2575(¶ 49).

Resistance: Resistance is a measure of the difficulty of passing an electric current through a conductor. Appx2343; Appx2575(¶ 50).

## **B. Circuit Components.**

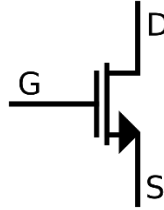
Circuit designers/engineers use circuit diagrams to illustrate how circuit elements are connected together. Each circuit element has a particular effect(s) on voltage, current, charge, and energy. By combining circuit elements in different numbers and/or ways and using circuit elements that have certain values, circuit designers/engineers can create circuits that perform a wide variety of different functions. Appx2344; Appx2578(¶ 59).

### **1. Transistor.**

A transistor is a semiconductor device that has at least three terminals for connection to an external circuit. Appx2344; Appx2578-2579(¶¶ 60-61).

A transistor is a versatile component and can be configured to perform completely *different* functions. *See* Section II.C below. This is an important point. For example, in one configuration, a transistor can operate as an amplifier to amplify electronic signals in a circuit. But in another different configuration, a transistor can operate as a switch to open and close a circuit based on a control signal. Whether a transistor is used as a switch or performs another function depends on the signals applied to the terminals of the transistor, and on the circuit in which the transistor is embedded. Appx2344; Appx2579(¶¶ 62-63).

A field-effect transistor (FET) is one type of transistor. Not all transistors are FETs. The symbol for one type of FET is shown below.



A FET has three terminals: (i) source (S), (ii) drain (D) and (iii) gate (G). In a FET, a voltage at the gate (G) controls the current flow between the drain (D) and source (S). Appx2344-2345; Appx2580(¶¶ 64-66).

## 2. Resistor.

A resistor is a circuit element that introduces resistance into a circuit. The symbol for one type of resistor is shown below.



Resistors are used, for example, to reduce current flow, adjust signal levels, divide voltages, bias active elements, and terminate transmission lines. Appx2345; Appx2583-2584(¶¶ 79-82).

## 3. Diode.

A diode is a two-terminal electrical component that allows the flow of current in only *one* direction similar to a one-way valve. It offers low (negligible) resistance in one direction (to allow current flow) and high resistance in the reverse direction (to prevent current flow). The most common type of diode is made from a

combination of p-type semiconductor material and n-type semiconductor material, known as a p-n junction. The symbol for one type of diode is shown below.

Appx2345; Appx2584(¶ 83).



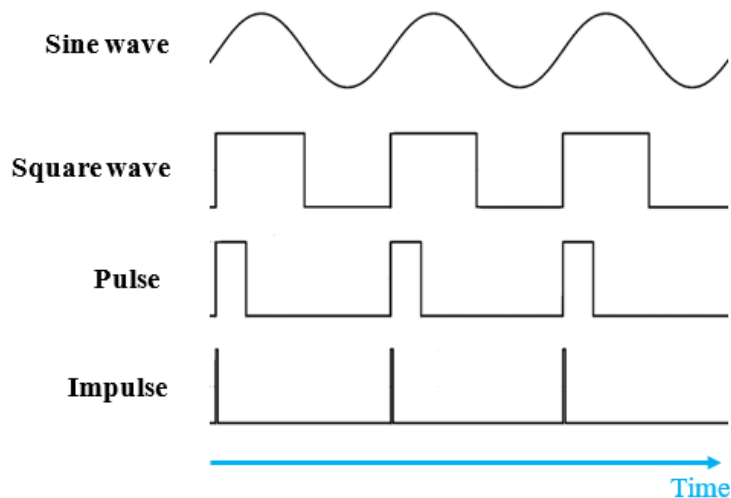
Current flows through the diode from the anode (positive (+ or “p”) lead) to the cathode (negative (- or “n”) lead). As shown above, the arrowhead points in the direction of the current flow. Appx2346; Appx2584(¶ 84).

When a voltage source is connected to a diode such that the positive terminal of the source is connected to the anode (+) and the negative terminal to the cathode (-), the diode is said to be “forward-biased.” When the voltage across the diode becomes greater than a forward barrier potential, the diode becomes a conductor and allows current to flow in only one direction – from the anode to the cathode. Appx2346; Appx2584-2585(¶ 85).

When a voltage source is connected to a diode such that the negative terminal of the source is connected to the (+) anode and the positive terminal to the cathode (-), the diode is said to be “reverse-biased.” In this configuration, no current can flow through the diode unless the electric field is so high that the diode breaks down. Appx2346; Appx2585(¶ 86).

#### 4. Local Oscillator.

An oscillator is “[s]omething that oscillates,” i.e., “repeat[s] a cycle of motions or to pass through a cycle of state with strict periodicity.” Appx2585(¶ 87). “In particular, [an oscillator is] a self-excited electronic circuit whose output voltage or current is a periodic function of time [and is a] generator of an alternating signal, continuous, sinusoidal or pulsed.” *Id.* The terms “local oscillator,” “LO,” or “LO circuit” are used to refer to the local oscillator circuit. *Id.* The output signal of a local oscillator is commonly referred to as the “LO,” “LO signal” or “local oscillator signal.” Appx2585-2586(¶ 88).



The diagram above shows different types of LO signals that can be generated by a local oscillator. The signal can be (1) a sine or sinusoidal wave, (2) a square wave, (3) a pulse or (4) an impulse. A square wave, pulse and impulse are each periodic repetition of pulses. Appx2347; Appx2586(¶ 89).

As shown above, a sine or sinusoidal wave is a continuous signal with a value that changes smoothly over time. A square wave, train of pulses and train of impulses are each a signal that has two values, and unlike a sine wave, has abrupt transitions between those values. Appx2347; Appx2586-2587(¶¶ 90-92).

### **C. Operation of FETs – understanding why the Board erred**

The operation of transistors and, in particular, FETs is *key* to understanding why Intel's prior art references do not invalidate the challenged claims of the '108 patent.

#### **1. Overview**

A FET is a type of transistor that can be configured in different ways to act as completely *different* components – e.g., (1) an amplifier or (2) a switch or (3) a resistor. For example, when configured one way, a FET can operate as an amplifier to amplify a signal passing between two terminals of the FET. When configured another way, a FET can operate as a switch to turn the flow of current (between two terminals) on or off. A FET can amplify, switch, *or* oscillate the flow of current between two terminals by varying the current or voltage at a third terminal. In other words, a FET can behave and be used as *different* devices and in *different* ways. Appx2352; Appx2598(¶¶ 123-124).

The type of function that a FET performs, that is, the way in which a FET operates, depends on the LO signal (e.g., independent control input) that the FET

receives, how the FET is biased, and the circuit in which the FET is located. For example, if a FET receives a *sinusoidal wave* (i.e., a sinusoidal, continuous time-varying voltage) across its input terminals, a continuous time-varying current flows between its output terminals. In one such biasing arrangement, the FET functions as a continuous time-varying *resistor*. This mode of operation is referred to as time-varying transconductance (the reciprocal of time-varying resistance. Appx2352-2353; Appx2598-2599(¶¶ 125-126).

If, however, a *square* or a train of *pulses* is applied at the gate of a FET, the FET acts as a *switch* between the output pair of terminals. Appx2353; Appx2599(¶ 127).

## **2. Different uses of FETs.**

In order to understand the operation of a circuit, one must view the circuit as a whole and also look at the electrical signals in the circuit. One cannot simply look at individual components of the circuit. This is because the same components (e.g., transistors) used in different circuits can operate as different types of devices (e.g., an amplifier or a switch or a resistor) and be used in *different* ways depending on a number of characteristics or parameters that can be varied. As such, the way in which the components in a circuit are used is critical to what the circuit actually does. Appx2353; Appx2606(¶ 144).

The way in which a FET operates depends on the needs of the circuit/system. Appx2353; Appx2606(¶ 145).

**a. FETs used in a switching system.**

When a FET is used as a switch, the FET opens and closes. When the FET is ON (closed), current can pass through the FET; when the FET is OFF (opened), current cannot pass through the FET. Said another way, a FET used as a switch has two states – either ON (closed) or OFF (opened); allowing all current through or preventing current from flowing. Appx2353; Appx2607(¶ 146).

**b. FETs used in an amplifier.**

In the late 1990s, another way FETs were used was in an amplifier circuit to amplify a signal. FETs used in an amplifier circuit must be biased, which refers to the addition of a constant voltage, i.e., the bias voltage, to the input sinusoid signal. Varying the bias voltage changes the shape of the output waveform as well as the amount of power consumed by the circuit. Appx2355; Appx2608(¶ 151).

Unlike a FET used as a switch, a FET used in an amplifier circuit amplifies a signal – a FET in this configuration does not open and close; it does not have two states; it does not prevent current from flowing. Importantly, as an amplifier, a small voltage variation at the gate of the FET results in a large variation at the drain of the FET. A FET amplifier has gain, while a FET used as a switch does not. Appx2355; Appx2608-2609(¶ 151).

### **III. THE '108 PATENT**

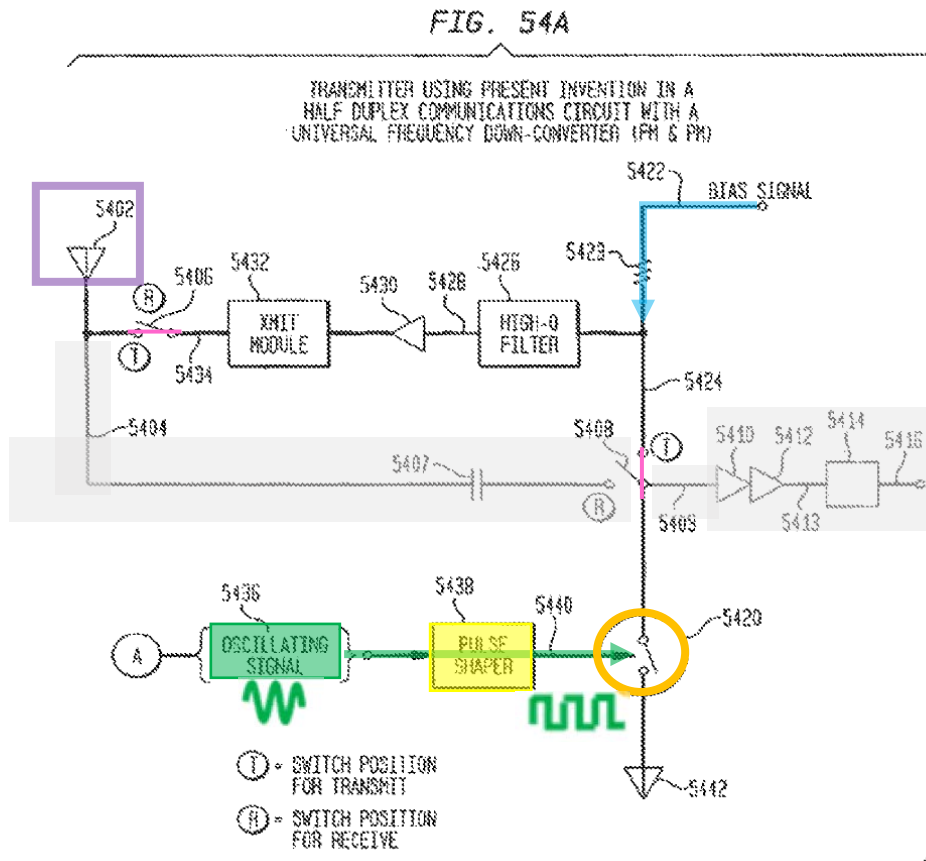
#### **A. Overview**

The '108 patent relates to systems and methods to up-convert a signal from a lower frequency to a higher frequency. Appx153(1:65-67); Appx2355; Appx2609(¶ 153).

Figure 54A of the '108 patent (below) illustrates components of an exemplary up-conversion system, which would be incorporated into a transceiver chip of a wireless device.<sup>3</sup> The up-conversion system includes a switch 5420 (orange), a control signal (green), a bias signal 5422 (blue) and an antenna 5402 (purple). Appx2356; Appx2609(¶ 153).

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<sup>3</sup> Figure 54A illustrates components of both up-conversion (transmission) and down-conversion (reception) systems. The down-conversion (reception) system components are grayed out as they are not relevant to a discussion of the up-conversion (transmission) system. Appx2356.



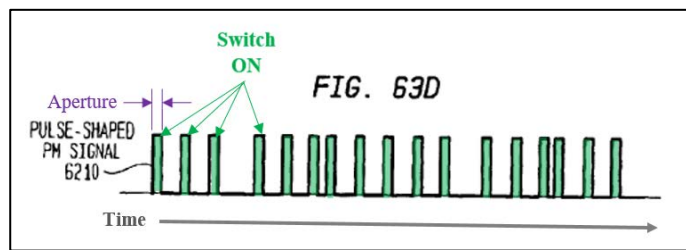
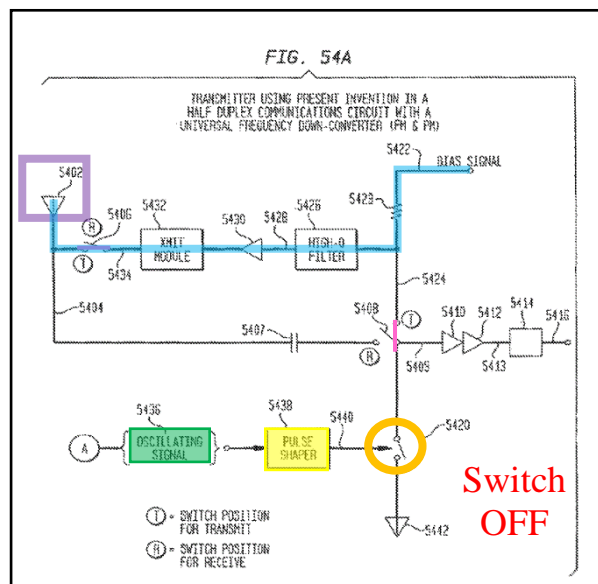
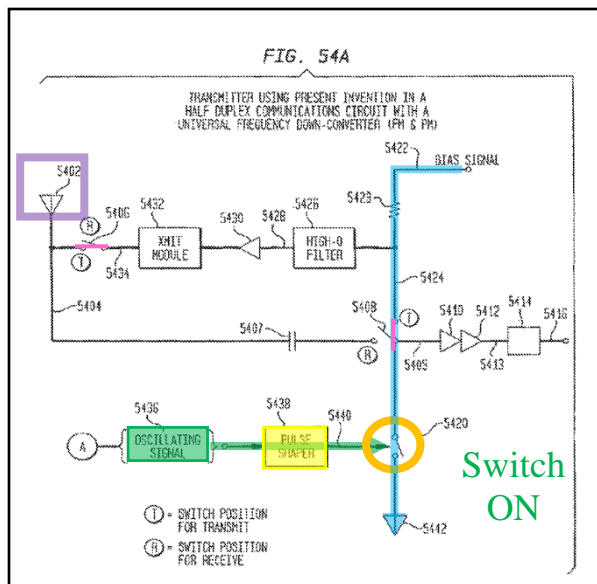
As shown above, in the transmit mode, switches 5406 and 5408 are positioned as shown by the pink lines.<sup>4</sup> An oscillator (not shown) generates an

<sup>4</sup> Figure 54A uses the symbol ① to represent the switch position for signal transmission and the symbol ② to represent the switch position for signal reception. The switches are positioned towards the ① during transmission and towards the ② during reception. Appx2356.

oscillating (sinusoidal) signal 5436 (green sinusoidal waveform),<sup>5</sup> which is transmitted to and shaped by the pulse shaper 5438 (yellow) into a string of pulses 5440 (green square waveform). The string of pulses 5440 controls the opening and closing of the switch 5420 (orange). Appx2357; Appx2610-2611(¶ 154).

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<sup>5</sup> In the FM modulation mode, an information signal 5450 is connected by switch 5446 to voltage-controlled oscillator (VCO) 5444 to create a frequency modulated oscillating signal 5436. *See* Appx139(Fig. 54B); Appx2357. In the PM modulation mode, switch 5452 connects information signal 5450 to the phase modulator 5456 to create a phase modulated oscillating signal 5436. *See* Appx139(Fig. 54C); Appx2357.



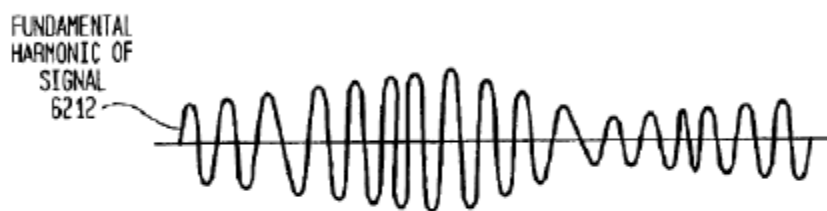
The annotations in FIG. 54A above illustrate how information (baseband/low frequency signals) is up-converted to a high frequency RF signal (modulated carrier signal). In particular, up-conversion occurs by repetitively turning the switch 5420 ON (closed) and OFF (opened). Appx2358; Appx2612(¶ 155).

As shown in FIG. 63D above, the switch is turned ON (closed) by sending a pulse (green) to the switch. The switch is kept ON (kept closed) for the duration of the pulse (i.e., during an aperture (purple) of the pulse). As shown by the repetitive string of pulses, this opening/closing of the switch continues over time. Appx2358; Appx2612(¶ 156).

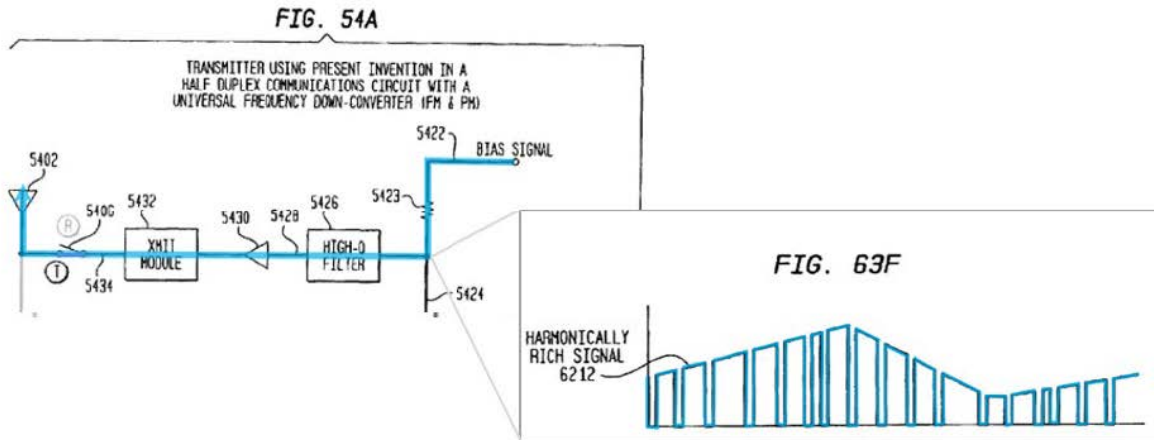
As shown in FIG. 54A (above left), when the switch is ON (closed) during the aperture, the bias signal 5422 (blue) passes to ground 5442. As shown in FIG. 54A (above right), between pulse apertures, the switch is turned OFF (opened) and the bias signal 5422 (blue) is sent to the antenna 5402. Appx2359; Appx2612(¶ 157).



FIG. 63E above (left) illustrates an exemplary reference (bias) signal 6206. As shown in FIG. 63F above (right), repetitively turning the switch ON (closed) and OFF (open) affects the shape of reference (bias) signal 6206, resulting in a square wave signal 6212. The valleys in the signal 6212 are created when the switch is turned ON (closed) and portions of the reference (bias) signal passes to ground 5422. The peaks in the signal 6212 are created when the switch is turned OFF (opened). Appx2359; Appx2612-2613(¶ 158).

*FIG. 63G**FIG. 63H*

Signal 6212 (shown in FIG. 63F) is referred to as a harmonically rich signal because the signal 6212 is actually made up of harmonics that are integer multiples of the fundamental frequency of the periodic signal itself. For example, FIGS. 63G-H illustrate harmonically rich signal 6212 comprising a plurality of harmonics, in this case the first harmonic (the fundamental frequency), and the second harmonic (two times the fundamental frequency). The combination of sinusoidal signals (harmonics) forms the signal 6212. Appx2360; Appx2613(¶ 159).



As shown above, the harmonically rich signal 6212 (FIG. 63F) passes through a filter 5426 on its way to the antenna 5402. The filter 5426 removes unwanted frequencies that exist as harmonic components of harmonically rich signal. As shown in FIG. 54A, desired frequency 5428 is amplified by amplifier module 5430 and routed to transmission module 5432 which outputs a transmission signal 5434. Appx2361; Appx2614(¶ 160).

#### IV. PRIOR ART REFERENCES.

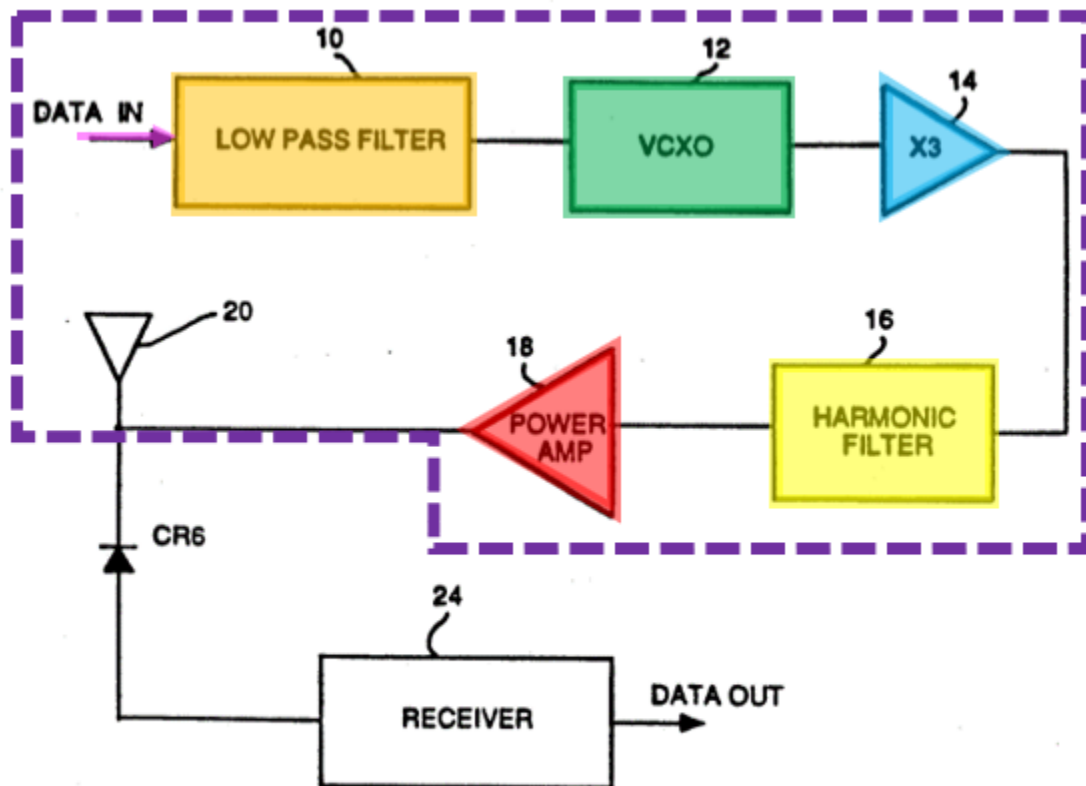
##### A. U.S. Patent No. 5,239,686 (“Downey”)

U.S. Patent No. 5,239,686 to Walter J. Downey (“Downey”) issued on August 24, 1993, and is entitled “Transceiver with Rapid Mode Switching Capability.” Appx441; Appx2367; Appx2616-2617(¶ 167).

##### 1. Overview.

The “Background of the Invention” section begins by noting that “an RF transceiver requires that the transmitter section and receiver section be isolated

from one another in some manner so that sensitivity of the receiver is not unduly degraded by the relatively high power transmit signal.” Appx446(1:14-18); Appx2367. Downey discusses RF transceiver designs and the problems associated with existing solutions. Appx446(1:14-50); Appx2367. Downey proposes an RF transceiver that purportedly solves these issues. Appx446(1:60-66); Appx2367. In particular, Downey discloses an RF transceiver that “achieves fast switching time between transmit and receive modes by leaving the transmit oscillator on all the time.” Appx446(1:61-63); Appx2367.



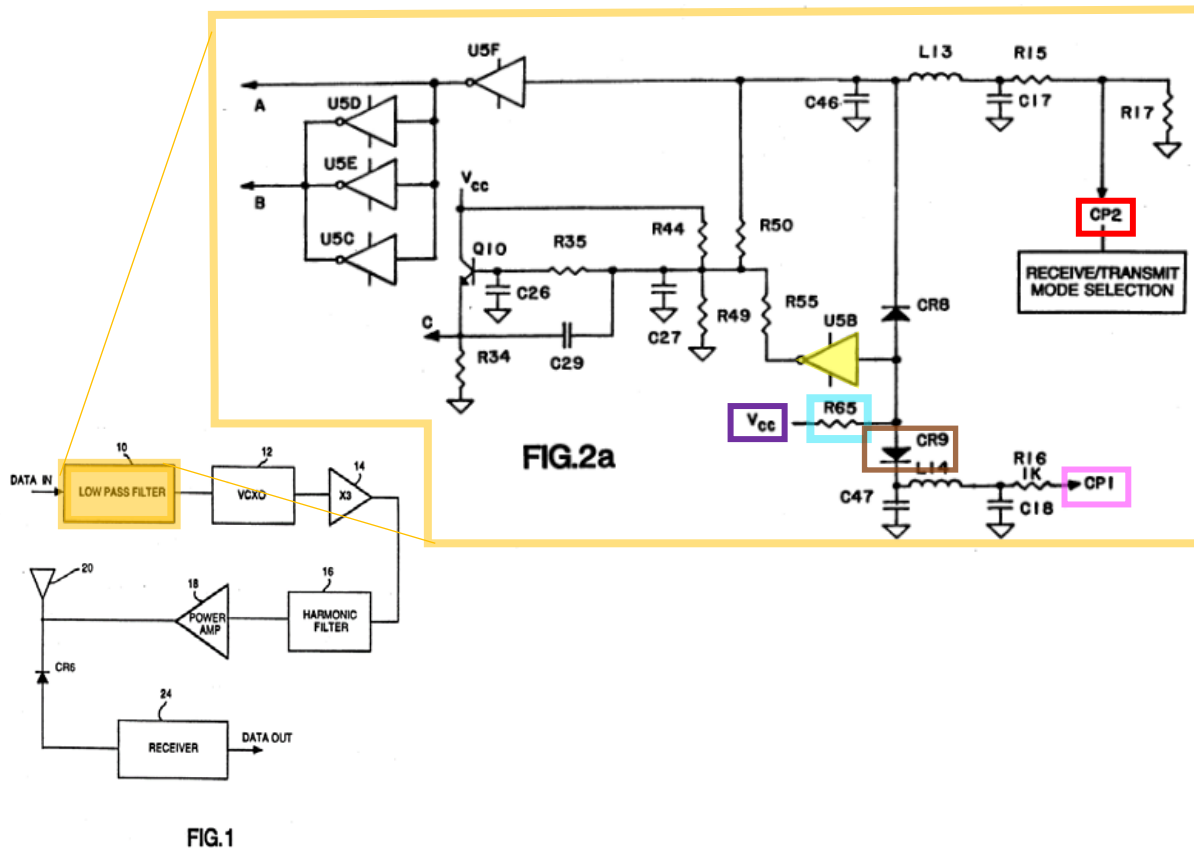
**FIG. 1**

As shown above, FIG. 1 of Downey illustrates a functional block diagram of an RF transceiver. The transmit-side or transmit chain of the RF transceiver (indicated by the purple dashed box) includes a low pass filter 10 (orange), voltage-controlled crystal oscillator (VCXO) 12 (green), frequency tripler 14 (blue), harmonic filter 16 (yellow), power amplifier 18 (red), and antenna 20. Appx446-447(2:53-3:13); Appx2368.

A digital information signal (i.e., data to be transmitted on a communications network) (pink arrow) is supplied from a processing unit (not shown) to low pass filter 10 (orange). The low pass filter 10 (orange) removes high frequency components of the digital information signal before modulation of an RF signal at VCXO 12 (green). Appx446(2:54-60); Appx2368-2369. The modulated RF signal is subsequently passed to frequency tripler (X3) 14 (blue) and harmonic filter 16 (yellow), which “generate sufficient energy” and selectively pass “the third harmonic (at the communication frequency of the transceiver).” Appx446-447(2:53-3:5); Appx2369. The RF signal is then asserted at power amplifier 18 (red) which boosts power of the signal for transmission on a communications network. The power amplifier 18 is coupled to antenna 20 which radiates the transmit signal. Appx447(3:5-10); Appx2369.

## 2. Low pass filter.

FIG. 2a of Downey (below) illustrates the circuitry for implementing low pass filter 10 (orange box) shown in FIG. 1.



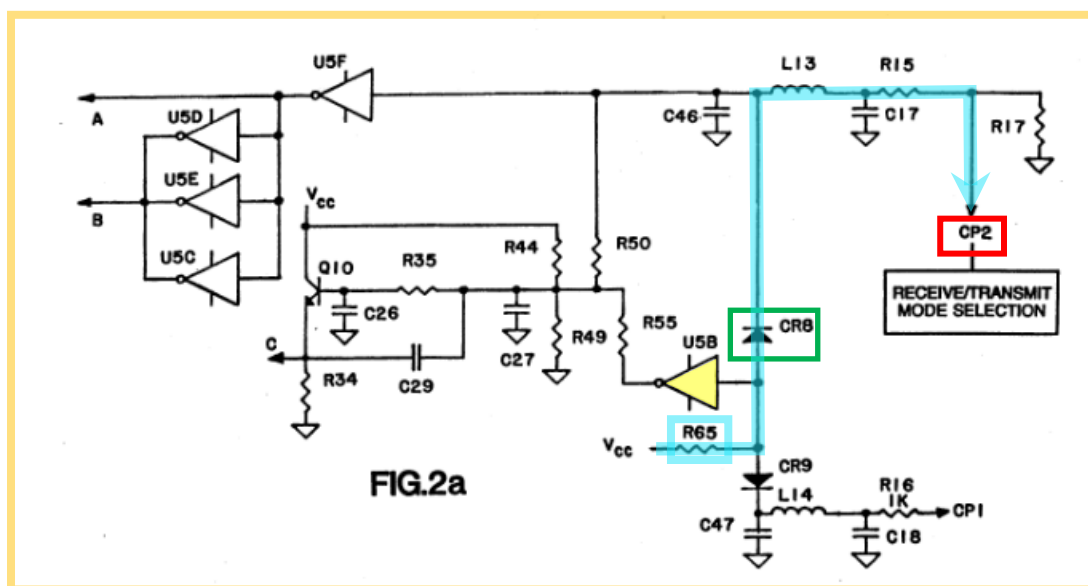
As shown above, a power supply voltage  $V_{cc}$  (purple box) is applied through resistor R65 (blue box), resulting in current flow. The path the current takes through the low pass filter 10 depends on the voltage applied to connector pins CP1 (pink box) and CP2 (red box). Depending on the voltage applied to connector pin CP2 (red box), connector pin CP2 causes the low pass filter 10 to operate in either a “transmit” mode or a “receive” mode. Appx447(3:38-43) (“A logical zero at CP2 places the transceiver in the receive mode, whereas a logical

one places the transceiver in the transmit mode.”). The voltage applied to the connector pin CP1 (pink box) causes current to flow along one of two paths in the transmit mode.

**a. Receive mode.**

To operate the low pass filter 10 in “receive” mode (as shown below), there is no input at connector pin CP2 (red box) (i.e., connector pin CP2 = 0V). In this configuration, diode CR8 (green box) is forward-biased, which allows current to flow (shown along the blue path) to connector pin CP2 through diode CR8.

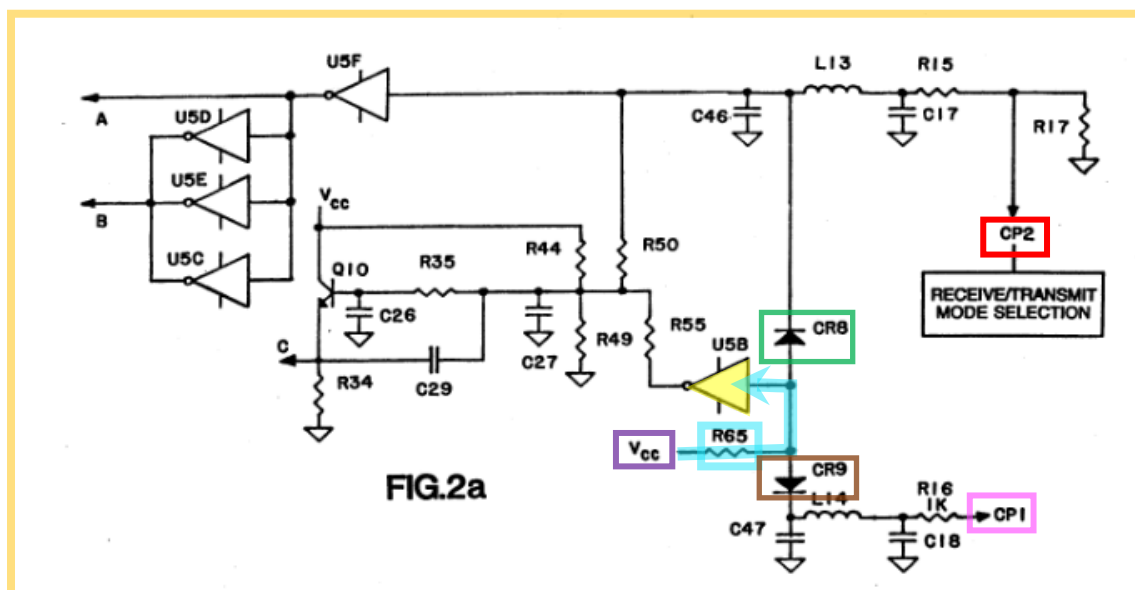
Appx2371.



**b. Transmit mode.**

To operate the low pass filter 10 in “transmit” mode, a voltage is applied to connector pin CP2 (red box) (i.e., connector pin CP2 = 5V). In this configuration,

diode CR8 (green box) is no longer forward-biased, and current cannot pass through diode CR8.



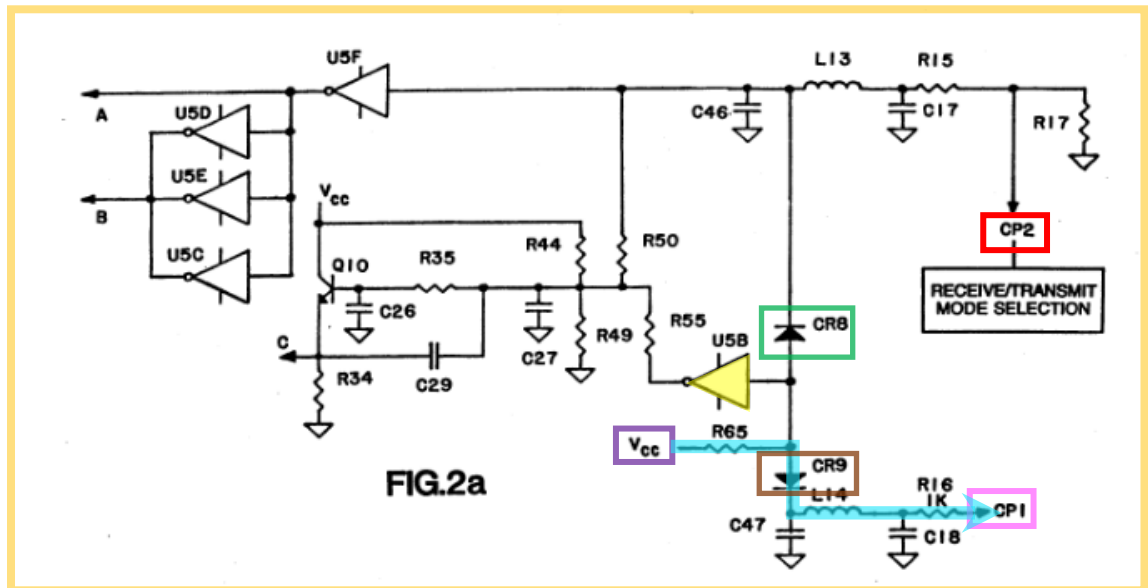
Once in “transmit” mode, current through resistor R65 (blue box) can flow along one of two paths depending on the voltage applied to connector pin CP1 (pink box).<sup>6</sup>

The diagram above illustrates the first path along which current flows when low pass filter 10 is in “transmit” mode. When a voltage is applied to connector pin CP1 (pink box) (i.e., CP1 = 5V), diode CR9 (brown box) is no longer forward-

<sup>6</sup> A digital information signal is received at connector pin CP1 (pink box) and includes “a stream of digital bits with logical ones and logical zeros represented by approximate nominal voltages of five volts and zero volts, respectively.”

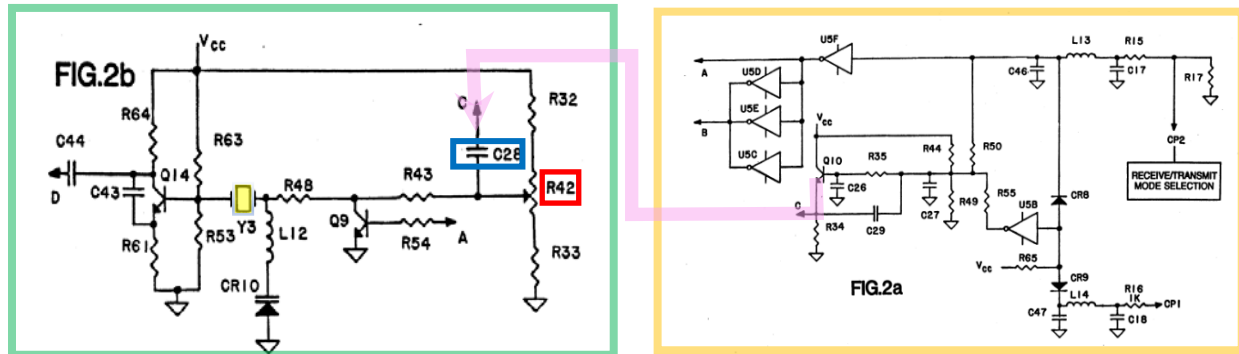
Appx2370; Appx447(3:24-27).

biased and, thus is non-conducting (i.e., current cannot flow through diode CR9). Because both diode CR8 (green box) and diode CR9 (brown box) are non-conducting in this configuration, current flows (shown along the blue path) toward inverter U5B (yellow triangle) and the input voltage at inverter U5B approximates  $V_{CC}$  (purple box). Appx2372.



The diagram above illustrates the second path along which current flows when low pass filter 10 is in “transmit” mode. When no voltage is applied to connector pin CP1 (pink box) (i.e.,  $CP1 = 0V$ ), diode CR9 (brown box) is forward-biased and, thus, as shown by the blue arrow, current flows to connector pin CP1 through diode CR9 (along the blue path). Appx2372.

### 3. Low pass filter to VCXO.



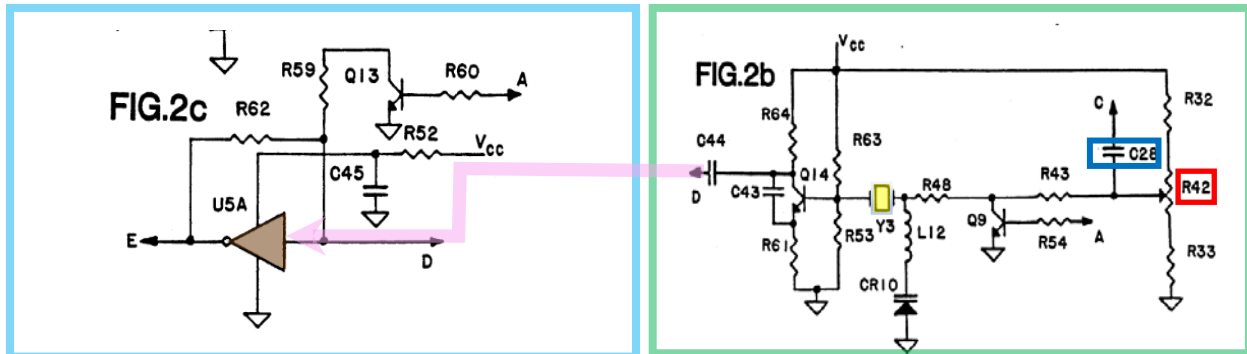
As shown above, signal C (pink arrow) (which is developed at emitter Q10) is outputted from the low pass filter (FIG. 2a, orange box) and sent to the VCXO 12 (FIG. 2b, green box). Appx2373.

As shown in FIG. 2b, the VCXO is driven by a crystal Y3 (yellow), which preferably operates at 16.628 MHz, or one third of the nominal 49.885 MHz communications frequency. Appx447(3:53-57); Appx2373. The operating frequency of the VCXO is adjustable by variable resistor R42 (red).

Appx447(3:57-59); Appx2373. Signal C (pink arrow) is coupled to the wiper contact of variable resistor R42 through capacitor C28 (blue box). Appx2373.

Downey teaches that because “the frequency of the oscillator is a function of the voltage at the wiper contact of resistor R42, the data signal from the low pass filter frequency modulates the oscillator output signal.” Appx447(3:61-65).

#### 4. VCXO to Frequency triplexer (X3).

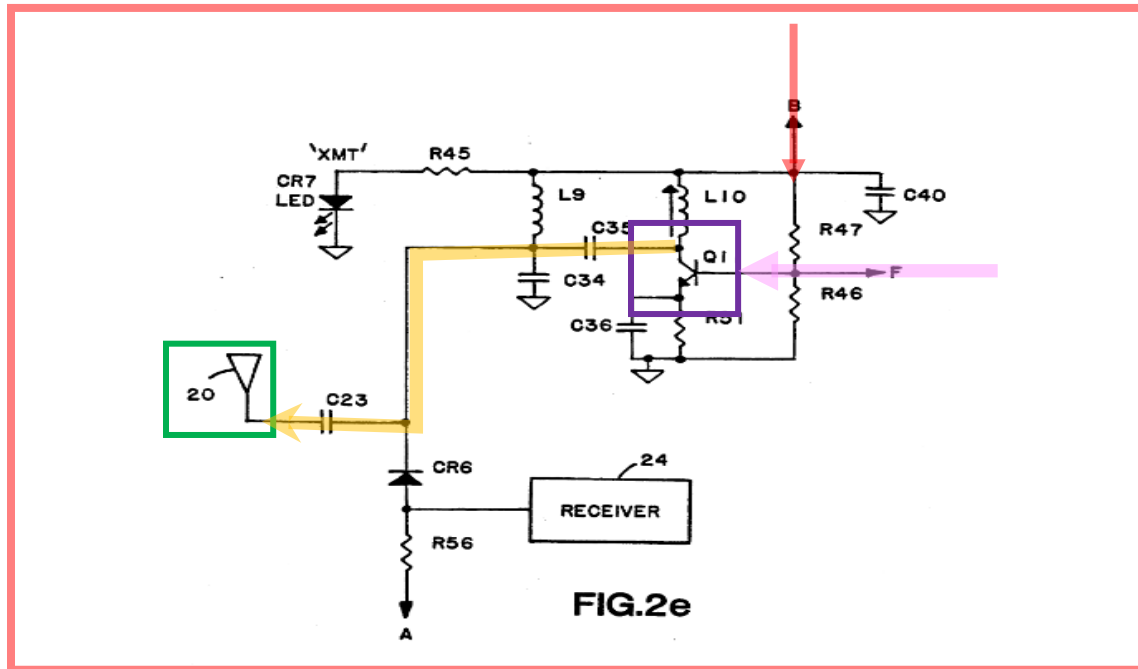


As shown above, signal D (pink arrow) is outputted from the VCXO 12 (FIG. 2b, green box) and sent to the frequency tripler 14 (FIG. 2c, blue box). Signal D is asserted at the input of inverter U5A (brown triangle). Appx2374. Notably, Downey teaches that inverter U5A “is operated as a non-linear amplifier to develop harmonics of the input signal, particularly the third harmonic which will drive the RF power amplifier.”<sup>7</sup> Appx447(4:10-13).

The output of inverter U5A (signal E) is applied to harmonic filter 16 which comprises components selected to pass the third harmonic of VCXO at the communication frequency. Appx447(4:20-25). The output of harmonic filter 16 (signal F, pink arrow below) is applied to power amplifier 16 (shown in FIG. 2e (below)).

<sup>7</sup> Unless otherwise noted all emphasis has been added.

## 5. Power amplifier.

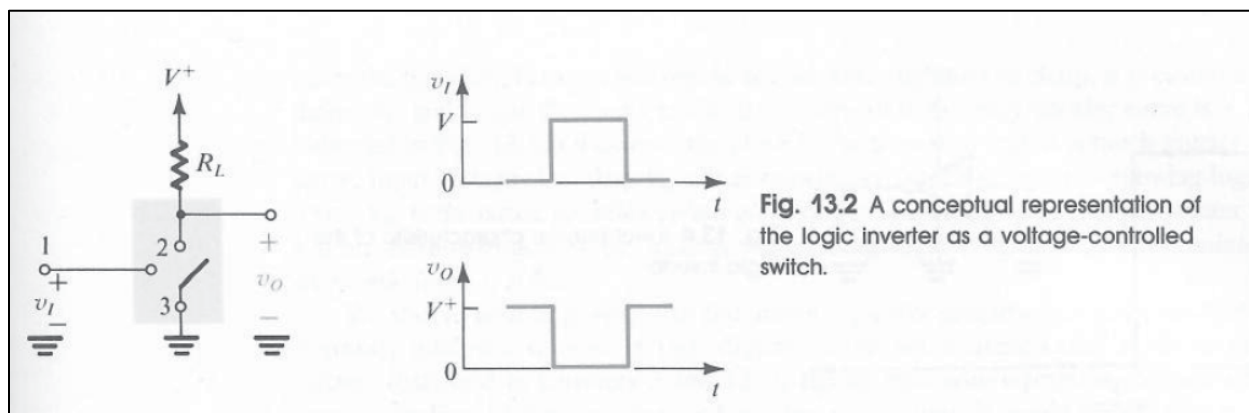


As shown in FIG. 2e, signal F (pink arrow, the output of the harmonic filter) is received at the power amplifier 18 (red box) and applied to the base of transistor Q11 (purple box). Appx2375. Signal B (red arrow) supplies voltage to transistor Q11. The power amplifier outputs a signal (orange arrow) to antenna 20 (green box) through capacitor C23. The antenna transmits the signal (orange arrow). *Id.*

### B. Sedra et al., “Microelectronic Circuits,” Third Edition (1991) (“Sedra”).

Sedra (Appx451-508) is an edited textbook and has a copyright date of 1991. Intel relies on Chapter 13.1 of Sedra which discusses basic logic-circuit concepts that apply to both MOSFET and BJT circuits. Appx2375.

As shown below in FIG. 13.2, Sedra teaches one implementation of a logic inverter.

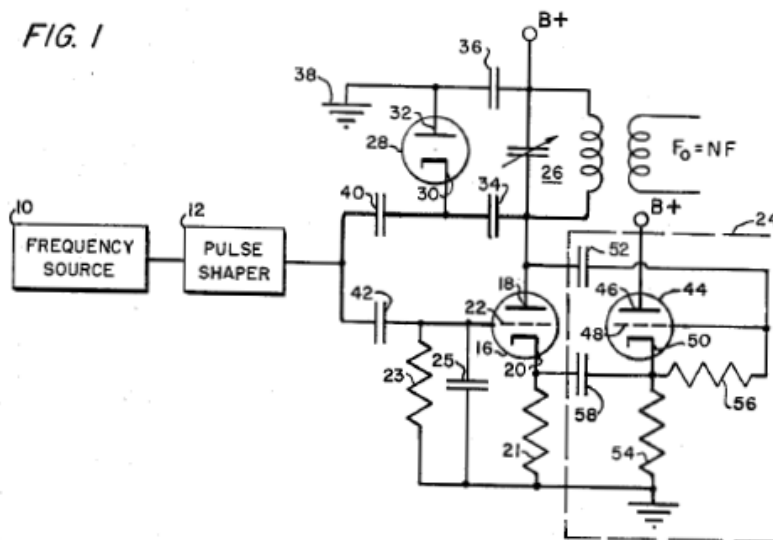


The transistor in Sedra's inverter is configured as a switch connected between terminals 2 and 3. Appx478. The switch is controlled by an input signal  $v_I$  that is a pulse. Terminal 3 is connected to the reference or ground point. *Id.* When  $v_I$  is low (around 0 V), the switch is open and the output voltage  $v_O$  is high (equal to the supply voltage  $V^+$ ). When  $v_I$  is high, the switch is closed, and the output voltage is low (around 0V). *Id.*

### C. U.S. Patent No. 2,730,624 ("Hahnel").

U.S. Patent No. 2,730,624 to Alwin Hahnel ("Hahnel") was filed on May 4, 1953 and is entitled "Frequency Multiplier Circuit." Appx509-512. Hahnel discloses a frequency multiplier and, in particular, a frequency multiplying circuit for selecting any high order multiplication factor. Appx2376.

Figure 1 of Hahnel (shown below) illustrates a schematic representation of a frequency multiplier circuit.



The frequency multiplier circuit includes a frequency source 10, a pulse shaper 12, and an electron discharge device 16 having an input circuit and an output circuit which includes means for selecting a desired harmonic frequency of the fundamental frequency. During gating pulses, the electron discharge device 16 is rendered conductive and shock-excited into oscillation at the selected harmonic frequency for the duration of the gating pulse. A regenerative feedback circuit 24 is connected between anode 18 and cathode 20 of the electron discharge device 16.

Appx2377.

## V. PROCEDURAL HISTORY.

### A. Intel's Petition.

Intel filed in Petition on January 14, 2021. The Petition alleged that claims 1 and 12 of the '108 patent were obvious over Downey in view of Sedra. Appx233.

Intel also alleged that claims 6-9 and 17-20 were obvious in view of Downey,

Sedra, and Hahnel. *Id.* In applying Downey in view of Sedra, the Petition asserted that inverter U5A of Downey (in combination with the teachings of Sedra) was the claimed “first switch,” diode CR9 of Downey was the claimed “second switch,” and transistor Q11 in the power amplifier of Downey was the claimed “third switch.” Appx233-259. Intel did *not* propose “switch” as a term for construction. Instead, with regard to the claimed “first switch,” Intel merely asserted that “[i]t was well-known in the art that an inverter is a switch” (Appx238); with regard to the claimed “second switch,” Intel merely asserted that “the ’108 patent specifically refers to diodes as switches.” (Appx253); and with regard to the claimed “third switch,” Intel merely asserted that transistor Q11 controls whether the antenna transmits the signal (Appx255). That was the entirety of Intel’s basis for arguing that Downey (in view of Sedra) met the claimed “switches.”

The Board instituted the IPR proceeding on July 22, 2021. Appx2258-2296.

**B. Patent Owner Response.**

On October 25, 2021, ParkerVision filed its Patent Owner Response (“POR”). Because two district courts – the U.S. District Court for the Western District of Texas (“District Court”) and the U.S. District Court for the Middle District of Florida – already construed the term “switch” as used in ParkerVision’s patents, ParkerVision adopted those courts’ construction of “switch”: “an

electronic device for opening and closing a circuit as dictated by an independent control input.” Appx2355-2337; 2363-2366.

ParkerVision asserted that the challenged claims were patentable over Downey, Sedra, and Hahnel because none of references discloses the claimed first, second, and third “switch.” ParkerVision argued that the circuit components Intel identifies as switches are amplifiers and diodes, which are not switches. Appx2334; Appx2378-2386.

**C. Intel’s Reply.**

Intel filed its Reply on February 4, 2022. For the first time, Intel provided a construction of “switch.” Appx2687-2689. Intel agreed that a “switch” is an electronic device for opening and closing a circuit. *Id.* In doing so, Intel introduced new theories regarding what is disclosed in the cited references and how the circuit elements meet the definition of a “switch.” Appx2691-2715.

**D. ParkerVision’s Sur-Reply.**

ParkerVision filed its Sur-Reply on March 17, 2022. ParkerVision noted that two district courts separately held that a “switch” is a device for opening/closing a circuit (or that has two states - open/closed) “as dictated by an independent control input.” Appx3525-3526. Moreover, based on the positions contained in its POR, ParkerVision refuted the arguments in Intel’s Reply and further explained why

none of Intel’s cited references disclose the claimed first, second or third “switch” under either parties’ construction. Appx3531-3550.

### **SUMMARY OF ARGUMENT**

The PTAB erred in construing “switch.” Thus, the PTAB erred in finding the challenged claims invalid in view of that erroneous construction.

But even if the PTAB’s construction was correct—which it is not—the PTAB still erred in finding that the challenged claims would have been obvious in light of Downey and Sedra. Not only is the PTAB’s finding based on impermissible hindsight, but the proposed combination would abandon the express teachings of Downey, change the basic principle of operation in Downey, and render Downey inoperable for its intended purpose. Moreover, Intel’s proposed combination does not disclose “a first switch configured to up-convert a signal.”

Further, the PTAB erred by basing its patentability decision on theories not presented in the Petition but, instead, were raised for the first time (and based on new evidence) in Intel’s Reply.

### **ARGUMENT**

#### **VI. STANDARDS OF REVIEW**

Obviousness is a legal question based on underlying findings of fact. *Univ. of Strathclyde v. Clear-Vu Lighting LLC*, 17 F.4th 155, 160 (Fed. Cir. 2021). The Court reviews the Board’s ultimate obviousness determination de novo and

underlying factual findings for substantial evidence. *LG Elecs. Inc. v. Immervision, Inc.*, Case No. 21-2037, 2022 U.S. App. LEXIS 18948, at \*11 (Fed. Cir. July 11, 2022). “The substantial evidence standard asks ‘whether a reasonable fact finder could have arrived at the agency’s decision.’” *OSI Pharms., LLC v. Apotex Inc.*, 939 F.3d 1375, 1381–82 (Fed. Cir. 2019) (quoting *In re Gartside*, 203 F.3d 1305, 1312 (Fed. Cir. 2000)).

“The PTAB’s evidentiary rulings are reviewed on the standard of abuse of discretion.” *Vidstream LLC v. Twitter, Inc.*, 981 F.3d 1060, 1064 (Fed. Cir. 2020) (citing *Belden Inc. v. Berk-Tek LLC*, 805 F.3d 1064, 1078 (Fed. Cir. 2015)). “Abuse of discretion arises if the ruling: ‘(1) is clearly unreasonable, arbitrary, or fanciful; (2) is based on an erroneous conclusion of law; (3) rests on clearly erroneous fact findings; or (4) follows from a record that contains no evidence on which the Board could rationally base its decision.’” *Vidstream*, 981 F.3d at 1064 (quoting *Chen v. Bouchard*, 347 F.3d 1299, 1307 (Fed. Cir. 2003)).

## **VII. PTAB’S INVALIDATION OF THE CHALLENGED CLAIMS WAS IMPROPER BECAUSE IT IS BASED ON AN INCORRECT CONSTRUCTION OF “SWITCH.”**

### **A. The PTAB’s construction of “switch” is wrong.**

The challenged claims include the term “switch.” Before the PTAB’s FWD, two District Courts had already considered the construction of “switch.” In view of the totality of the patent specification’s disclosure, both courts included the

language “*as dictated by an independent control input*” – language the PTAB omitted from its construction.

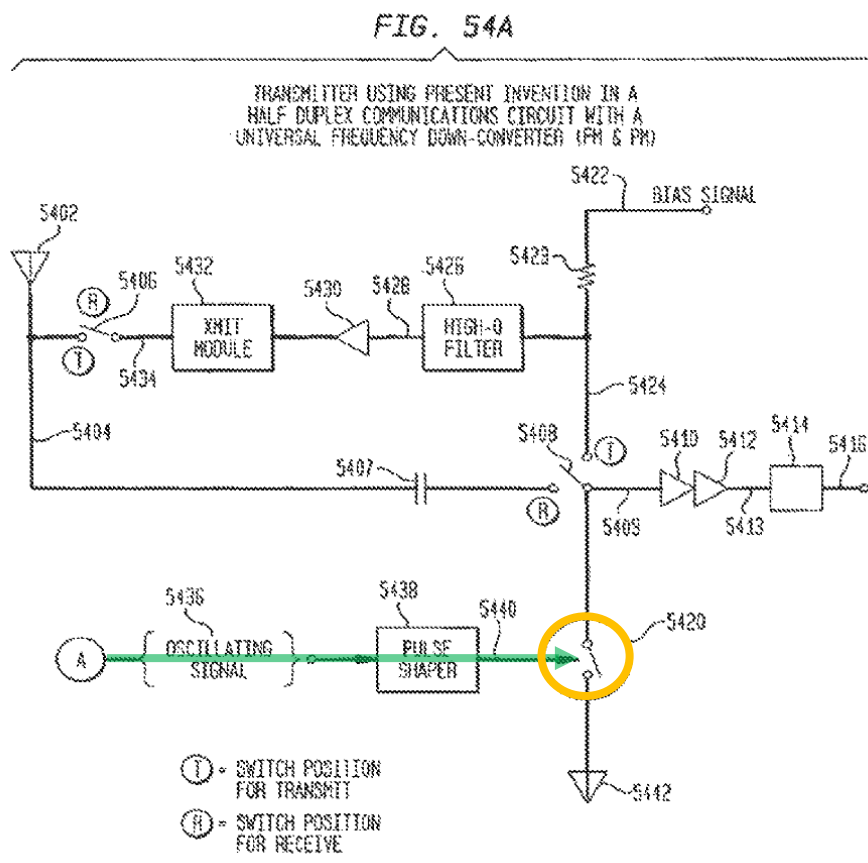
The U.S. District Court for the Western District of Texas (“Texas Court”) construed this term on *three* separate occasions in litigations against Intel, TCL and Hisense. The Texas Court consistently maintained its construction (which ParkerVision adopted as its proposed construction in the IPR) — “an electronic device for opening and closing a circuit *as dictated by an independent control input.*” Appx2392; Appx2412. *ParkerVision, Inc. v. Hisense Co., Ltd. et al.*, Case No. WDTX-6-20-cv-00870, D.I. 51 at 5 (W. D. Tex. Oct. 29, 2021).

In addition to the Texas Court, the U.S. District Court for the Middle District of Florida (Orlando Division) (“Orlando Court”) also construed the term “switch” in the context of ParkerVision’s patented technology. In a case ParkerVision brought against Qualcomm in the Orlando District Court (Case No. 6:14-cv-687), the parties disputed the meaning of the term “switch” with regard to U.S. Patent No. 6,091,940. The ’940 patent discloses the same type of up-conversion technology as set forth in the ’108 patent. Consistent with the Texas Court, the Orlando Court construed “switch” to be a “device with an input and output that can take two states, open and closed, *as dictated by an independent control input.*” Appx2438-2446.

The PTAB considered the exact same arguments that both the Texas and Orlando courts already considered. Both District Courts *rejected* the same arguments Intel made before the Board. But despite being aware of the District Courts' constructions, the PTAB afforded no deference to the District Courts and expressly rejected their construction of "switch." Instead, the PTAB found that "one of ordinary skill in the art would understand 'switch' to mean "an electronic device for opening and closing a circuit." Appx25-26. The PTAB's finding and rationale are wrong.

**B. The intrinsic evidence supports ParkerVision's construction.**

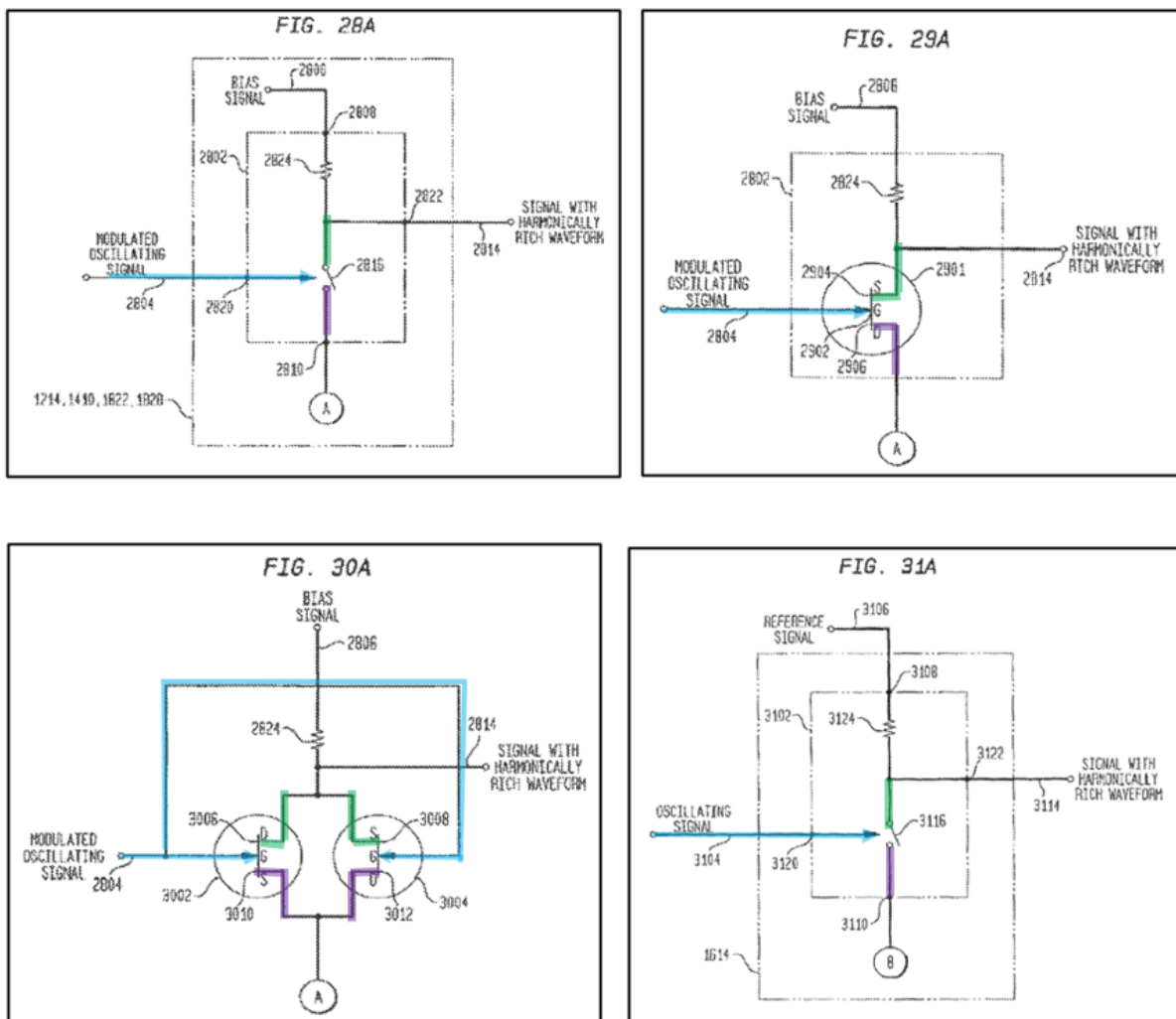
The patent specification makes it clear that a control signal is transmitted from a source external to the switch, thereby making opening and closing a circuit dictated by an independent control input. Appx2364.



For example, as shown in FIG. 54A above, an independent control input (green) is sent to switch 5420 (orange), which causes the switch 5420 to open and close. In particular, “[o]scillation signal 5436 is routed through pulse shaper 5438 to create a string of pulses 5440 which in turn cause switch 5420 to open and close.” Appx158(55:12-14); Appx2365. Indeed, contrary to the PTAB’s assertion that the specification discusses switches only as opening and closing (*see* Appx24), the ’108 patent is replete with disclosures indicating that the opening/closing of a switch is controlled by an independent control input. *See* Appx173(41:9-14) (“Another factor in assuring that the desired harmonic has sufficient amplitude is

how the switch 2816 and 3116 (FIGS. 28A and 31A) in the switch module 2802 and 3102 responds to the control signal that causes the switch to close and to open (i.e., the modulated oscillating signal 2804 of FIG. 28 and the oscillating signal 3104 of FIG. 31)”; Appx153(2:16-18) (“This *shaped signal* is then used to control a switch which opens and closes as a function of the frequency and pulse width of the shaped signal.”); Appx169(33:1-2) (“A modulated oscillating signal 2804 is connected to the control input 2820 of the switch module 2802.”); Appx179(54:7-8) (“The string of pulses 5311 controls the opening and closing of the switch 5312.”).

In addition to this repeated textual description in the specification, the ’108 patent figures also make it apparent that a switch is controlled by an independent control input.



As shown for example in Figures 28A, 29A, 30A, 31A (above), each disclosed embodiment in the '108 patent depicts a switch with an input (green), an output (purple), and an independent control input (blue). *See also* Appx120(Fig. 32A); Appx121(Fig. 33A); Appx138(Fig. 54A); Appx142-143(Figs. 57A-C). As such, the inclusion of the language “as dictated by an independent control input” is fully supported by the specification. *See In re Papst Licensing Digital Camera Patent Litig.*, 778 F.3d 1255, 1261 (Fed. Cir. 2015) (“The construction that stays

true to the claim language and most naturally aligns with the patent’s description of the invention will be, in the end, the correct construction.”).

In fact, ParkerVision’s construction comes directly from the specification’s disclosure, which describes what the patentees meant by controlling the switch – an independent control input causes the switch to open and close.

Control a switch: Causing a switch to open and close. The switch may be, without limitation, mechanical, electrical, electronic, optical, etc., or any combination thereof. Typically, it is controlled by an electrical or electronic input. **If the switch is controlled by an electronic signal, it is typically a different signal than the signals connected to either terminal of the switch.**

Appx156(7:57-63). The third sentence in the passage above explains that the control signal is typically electrical or electronic, as opposed to mechanical, optical, or some other manner. And the PTAB agrees. Appx21(“The third sentence refers back to ‘the switch’ just described in the second sentence using the pronoun ‘it’ and specifically states that ‘[t]ypically’ *the type of input* that may control the switch is ‘an electrical or electronic input.’.... [T]he ’108 patent expressly leaves open the option that the described switch may be controlled *with an input* that is not electrical or electronic.”) (emphasis added).

Notably, the PTAB does not dispute that, in the context of the claims, a switch is an electronic device that is *always* controlled by a control input. *See*

Appx21-23. But the PTAB points to the last sentence in the passage above (shown in red) and asserts that this one sentence, standing alone, justifies excluding “*independent control input*” from the construction of “switch.”

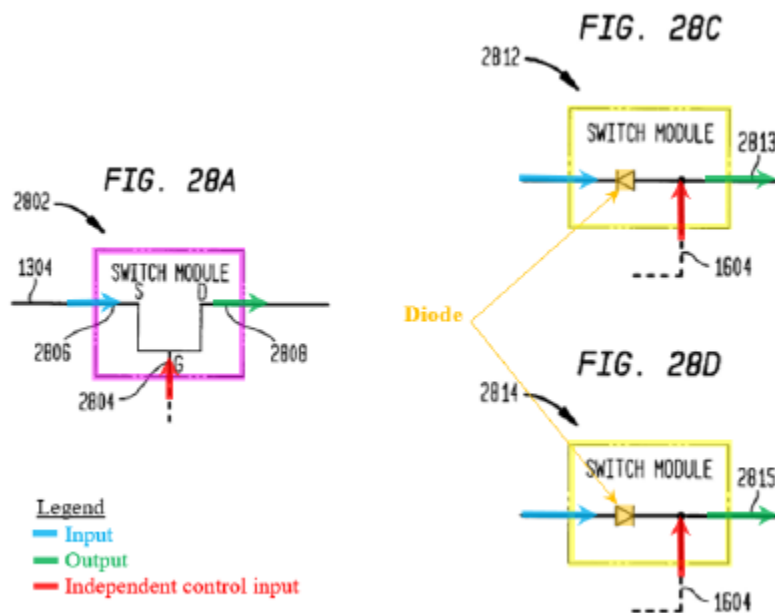
But, as explained below, the Board’s reliance on, and misreading of the last sentence (in red above), is not only wrong but cannot negate the entirety of the specification’s teachings regarding “switch.” *See, e.g., Baxalta Inc. v. Genentech, Inc.*, 972 F.3d 1341, 1346-47 (Fed. Cir. 2020).

**C. The Board’s construction is technically and legally wrong.**

The PTAB’s construction improperly omits the concept that the opening/closing of a switch is “dictated by an independent control input.” The PTAB places too much emphasis on a single sentence in the specification (shown in red above) to the exclusion of the complete disclosure in the specification. Though the PTAB claims to be adhering to the patentee’s lexicography, it is *not*.

This last sentence alone (in red above) is not a lexicographic definition of switch. It is one sentence that is part of the specification’s entire teachings regarding the switch. And notably, this last sentence refers to a *signal*, not an *input*; it merely describes how an electronic control *signal* is typically connected to the switch; it does not suggest that the control input need not always be “independent” as the PTAB contends. Appx23.

The PTAB's analysis is misguided because the PTAB conflates "a different *signal* than the signals connected to either terminal of the switch" with "an independent control *input*." But these are two separate concepts. As ParkerVision explained in its POR, an independent control input is transmitted from a source external to the switch. Appx2364. In other words, an independent control input is an input separate from the input or output of the switch. Appx3527; Appx2365-2366; Appx180(55:12-14); Appx173(41:9-14). This does not mean that an independent control input cannot be connected to an input/output terminal of the switch, as the PTAB contends. In fact, the PTAB's interpretation is completely at odds with the incorporated disclosure of U.S. Patent No. 6,061,551 ("the '551 patent"), which identifies a "diode switch" (shown in Figures 28C, 28D (below)) as an embodiment of a "switch module."



Appx1430.

As shown in Figures 28C and 28D (above right), the “diode switch” (which the patent identifies as the *entire* yellow box)<sup>8</sup> has three ports – an input (blue arrow), an output (green arrow) and an independent control input (a second input port) (red arrow). Appx3548. It is the “independent control input” that causes the opening and closing of the circuit. And at the same time the control input (red arrow) is both “independent” and connected to either terminal of the switch. Indeed, this configuration is similar to Figure 28A (above left) and Figure 28B, the

<sup>8</sup> To the extent that the PTAB relied on the diode (orange) by itself as the switch, such an assertion is wrong. The patent makes it clear that the diode is merely a component *within* a switch.

only other types of switch module (purple box) shown and described in the specification. But it is the configuration in Figure 28B, wherein the independent control input is connected to a gate rather than either terminal of the switch, that the last sentence (shown in red) of the passage above refers to as typical.

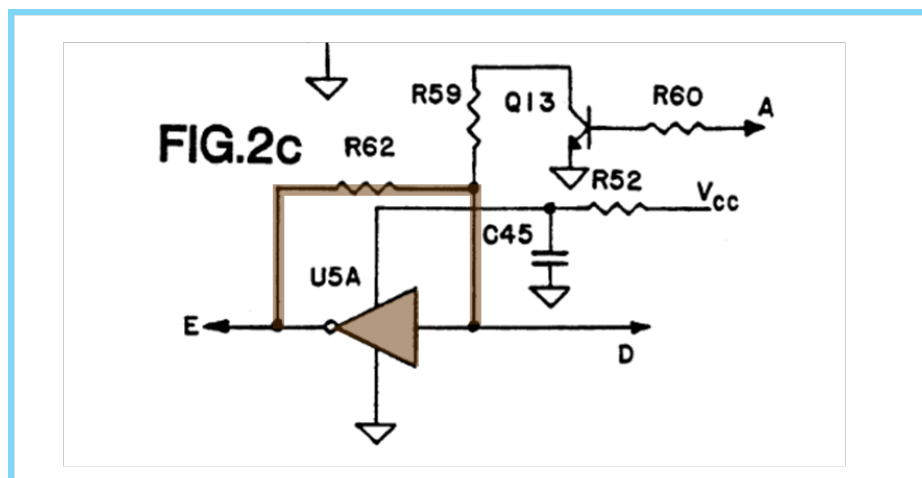
When applying the proper construction, Downey (in view of Sedra) does not disclose a first, second or third “switch.” Therefore, the PTAB’s determination should be reversed. Alternatively, and at a minimum, this Court should vacate and remand to the Board for a determination under the proper construction.

#### **VIII. THE ’108 PATENT IS NOT OBVIOUS IN VIEW OF THE INTEL REFERENCES**

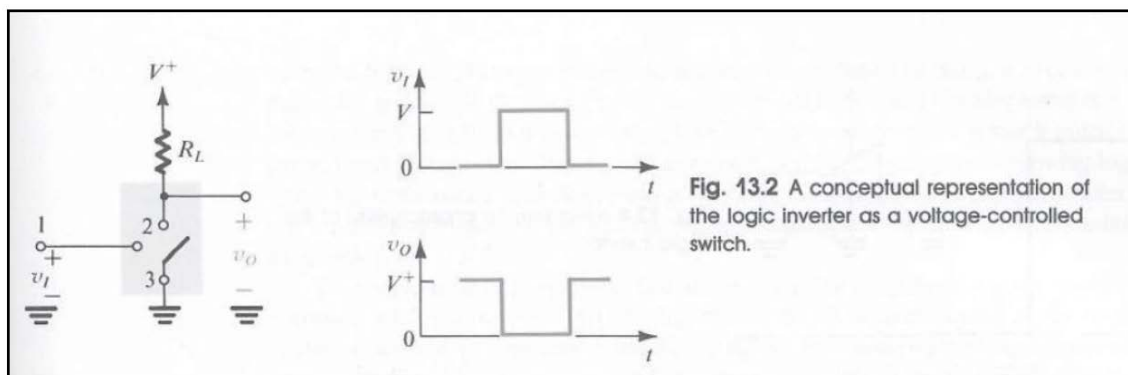
The Court should vacate the Board’s determination that the challenged claims are obvious. The ruling was both procedurally and substantively erroneous.

##### **A. The PTAB erred because Intel’s proposed combination of Downey and Sedra abandons the *express* teachings of Downey**

In the FWD, the PTAB found that it would have been obvious to modify Downey to replace inverter U5A with the inverter of Sedra. Appx39-46. In doing so, the PTAB ignored the critical function of inverter U5A in Downey.



Downey specifically discloses that inverter U5A (brown triangle) functions as an *amplifier* – inverter U5A “is operated as a non-linear amplifier to develop harmonics of the input signal, particularly the third harmonic which will drive the RF power amplifier.” Appx2374; Appx447(4:10-13). An *amplifier amplifies* a signal.



As shown above, the inverter of Sedra, on the other hand, operates as a *switch* (“voltage-controlled switch”). Appx2379; Appx478. Unlike an amplifier that *amplifies* a signal, the switch in Sedra performs a completely *different*

operation – opening/closing a circuit to either allow or prevent current from flowing. It is not obvious to replace an amplifier with a switch.

Indeed, an amplifier and a switch are completely *differently* components. Appx2382; Appx2632(¶ 199). And the inverter U5A cannot be replaced as a switch without rendering Downey’s circuit unsuitable for its intended purpose – to amplify a signal. Appx2380. Unlike a switch that transitions between being ON and OFF, Downey’s inverter configured as an amplifier is always ON. Appx2380-2381. ParkerVision’s expert explained that negative feedback (FIG. 2c above, brown path) ensures that the inverter in Downey is always biased ON (always closed): “a CMOS inverter with appropriate feedback ensures that the *transistor operates its active region* (i.e., *it is always ON/conducting current*).” Appx2381; Appx2632(¶ 198); Appx2550 (“The power supply current is constant during dynamic operation since the inverter is biased for Class A operation.”).

Not only was the PTAB’s (and Intel’s) replacement of Downey’s inverter with Sedra’s inverter done with hindsight of ParkerVision’s patent, but such reconfiguration of Downey requires abandoning/ignoring the *express* teaching of Downey to replace an amplifier circuit with a switch circuit. There is no reason to do so and the PTAB has not identified any reason.

**B. The PTAB failed to apply the proper legal standard.**

As this Court stated, “combinations that change the ‘basic principles under which the prior art was designed to operate,’ or that render the prior art ‘inoperable for its intended purpose’ may fail to support a conclusion of obviousness.” *Plas-Pak Industries v. Sulzer Mixpac AG*, 600 Fed. Appx. 755, 757-58 (Fed. Cir. 2013) (citing *In re Gordon*, 733 F.2d 900, 902 (Fed. Cir. 1984) (intended purpose); *In re Ratti*, 270 F.2d 810, 813 (C.C.P.A. 1959) (principle of operation)); *see also* MPEP 2143.01 V and VI. But Intel’s proposed combination does both.

Replacing Downey’s inverter U5A (configured as an amplifier that is always ON) with Sedra’s logic inverter (configured as a switch that toggles ON *and* OFF) would change the component’s fundamental principle of operation. With regard to the intended purpose of Downey, an amplifier provides gain (amplification factor), while a switch does not. Appx2355. When configured as an amplifier (as disclosed in Downey), the inverter “develop[s] harmonics of the input signal, particularly the third harmonic.” Appx2380; Appx447(4:10-13). But if the Downey inverter is configured as a switch (as disclosed in Sedra), the inverter simply realizes the logic inversion operation, which makes the new inverter inoperable for the intended purpose (amplification) as set forth in Downey. Appx478.

As discussed below, the PTAB’s findings on both these issues are legally erroneous and not supported by substantial evidence. For those reasons, the PTAB’s decision should be reversed, and the challenged claims held not invalid.

**1. Combining Downey with Sedra changes the basic principle of operation in Downey.**

The PTAB misapplied the relevant legal standard with regard to the principle of operation. The relevant question is whether the proposed combination would have the effect of altering the principle of operation of the prior art device being modified – here, Downey. The PTAB, however, never even considered the principle of operation of Downey in its analysis. Instead, the PTAB limited its analysis only to Sedra.

In particular, the PTAB found that Intel’s comparison of *Sedra’s inverter* with the *’108 patent’s up-conversion switch* to be “persuasive evidence that Petitioner’s *combined* circuit not only meets the claim limitation, but also looks and functions similar to the one disclosed in the *’108 patent Specification*.” Appx40-41. Yet, on its face, Intel’s comparison (and the Board’s) is limited to an analysis of an individual circuit—Sedra’s logic inverter. Neither Intel nor the PTAB analyzes how Sedra’s circuit would operate as modified in combination with Downey. Without that additional analysis, the PTAB’s review of Intel’s proposed combination was, at best, cursory and incomplete. This is not substantial

evidence necessary to invalidate a patent, and additionally, legal error – both warranting reversal.

Indeed, in limiting its analysis of Sedra alone, the PTAB overlooks the substantial evidence ParkerVision submitted regarding the operation of inverter U5A in Downey. As explained in the POR, Downey’s inverter U5A is not toggled between an open and closed state. Appx2380; Appx3538. Instead, as ParkerVision’s expert explained, the configuration of inverter U5A (with feedback) ensures that it operates in its active region (i.e., it is always ON/conducting current). Appx2381; Appx3538. The PTAB failed to address these points, among others.

**2. Combining Downey with Sedra renders Downey inoperable for its intended purpose.**

The intended purpose of Downey’s inverter is to act as an *amplifier* to *amplify* a signal. This is fundamentally different than an inverter configured as a *switch* (as disclosed in Sedra) which *allows or prevents current flow*. Regarding the intended purpose of Downey’s circuit, the PTAB’s findings are similarly clearly wrong. First, despite Downey’s explicit disclosure that “inverter U5A is operated as a non-linear amplifier to develop harmonics of the input signal,” the PTAB more broadly asserted that “it is the *non-linear operation* that allows Downey’s circuit to up-convert a signal and act as a frequency tripler.” Appx44. But the PTAB cited no evidence for ignoring the amplification operation of

inverter U5A in Downey to justify its conclusion. The PTAB's failure to recognize the "amplifier" aspect of inverter U5A's functionality and failure to support its purported finding with no evidence are clear errors.

Second, the PTAB alleged that "the inverter transfer characteristic of [Sedra's] inverter indicates that it is 'a grossly nonlinear device,' which is consistent with the mode that Downey states its inverter should operate in. Appx44 (citing Appx481; Appx447(4:10-13). But the PTAB conflates nonlinear devices and nonlinear operation of devices, which are distinct and separate concepts. A non-linear device is simply a device whose parameters are varied with respect to current and voltage. Appx2352. A nonlinear device can operate in both linear and/or nonlinear modes. A FET, for example, is a non-linear device. *Id.* Varying the parameters of a FET causes the FET to behave in different ways (e.g., as a linear *or* nonlinear amplifier). Appx481. Therefore, the fact that a device is a nonlinear device says nothing about its mode of operation, and because of that, there is no evidence supporting the Board's finding.

**C. The PTAB's obviousness determination to combine is based on impermissible hindsight.**

The PTAB's obviousness conclusion could only have been reached through hindsight. That is improper. "To imbue one of ordinary skill in the art with knowledge of the invention in suit, when no prior art reference or references of record convey or suggest that knowledge, is to fall victim to the insidious effect of

a hindsight syndrome wherein that which only the inventor taught is used against its teacher.” *W.L. Gore & Associates, Inc. v. Garlock, Inc.*, 721 F.2d 1540, 1553 (Fed. Cir. 1983). But this is exactly what has happened here.

The PTAB based its obviousness determination, in part, on a finding that “a person of ordinary skill in the art would have been motivated to combine the teachings of Downey and Sedra, including because Sedra accomplishes Downey’s goal of providing a compact transceiver by using small and energy efficient MOS transistors.” Appx42. The problem here is that Downey already discloses the use of MOS transistors in inverter U5A. Downey specifically identifies inverter U5A as component part no. 74HC04, the implementation details of which are described in Appx2550-2553. Appx3532; Appx47(5:21); Appx2381. During his deposition, Intel’s expert confirmed this. Appx3532; Appx3583(110:15-22); Appx3586(123:10-124:20). Part No. 74HC04 (and, thus, inverter U5A) is a CMOS inverter, which “incorporates a P-channel MOS transistor and an N-channel MOS transistor connected in complementary fashion.” Appx2550; Appx3588(129:8-21). Thus, based on the agreement between both parties’ experts, there is no reason whatsoever to modify Downey based on Sedra to include MOS transistors. Downey already provided the benefit that would allegedly be achieved by Intel’s proposed combination of Sedra. This unexplained redundancy underscores the fact that the PTAB’s motivation to combine is the result of impermissible hindsight.

The PTAB finding Intel’s comparison of Sedra’s inverter with the ’108 patent’s up-conversion switch as “persuasive evidence that Petitioner’s combined circuit ... looks and functions similar to the one disclosed in the ’108 patent Specification,” is also telling. It confirms the use of hindsight by using the patent itself as a roadmap for replacing Downey’s inverter with the inverter in Sedra. It is undisputed that Sedra’s inverter does not perform up-conversion. Yet, the PTAB found Sedra’s inverter and the ’108 patent’s “up-conversion” switch to function in the same way. Because the PTAB arrived at its obviousness determination through impermissible hindsight, its decision should be reversed.

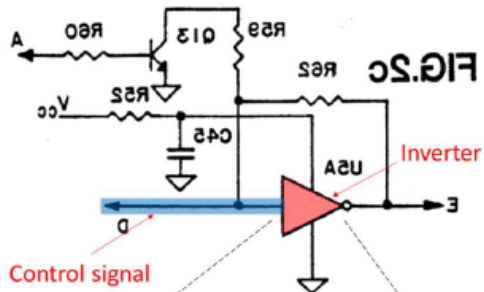
**D. The PTAB erred in finding Intel’s proposed combination discloses a “first switch.”**

Downey combined with Sedra does not disclose a “first switch.” As explained above, in practical effect, Intel’s proposed combination replaces one transistor for another transistor – replacing Downey’s inverter U5A (red triangle below) (which would include a transistor) with the transistor of Sedra.<sup>9</sup> This specific configuration is readily apparent in figures from Intel’s Petition (shown below).

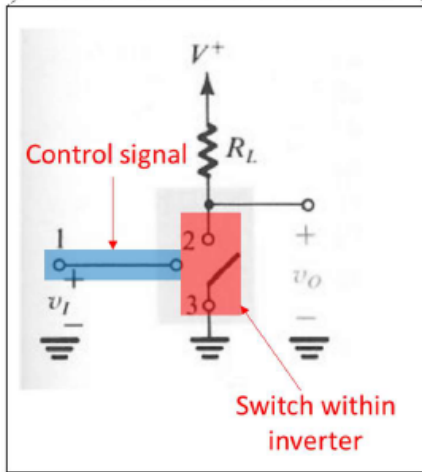
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<sup>9</sup> Both Intel and the PTAB have recognized that practical implementations of Sedra’s logic inverter utilize a transistor (a MOSFET or a BJT) as the switching element. Appx29; Appx227; Appx479.

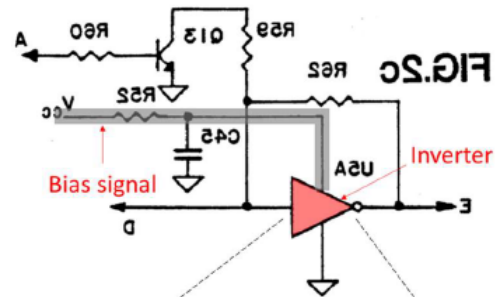
**Downey's Frequency Tripler  
(Mirror Image) (Fig. 2c) With  
Sedra's Switch (p. 909)**



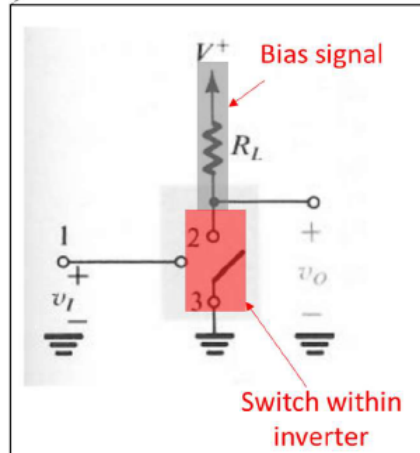
**Sedra's Switch Within Inverter**



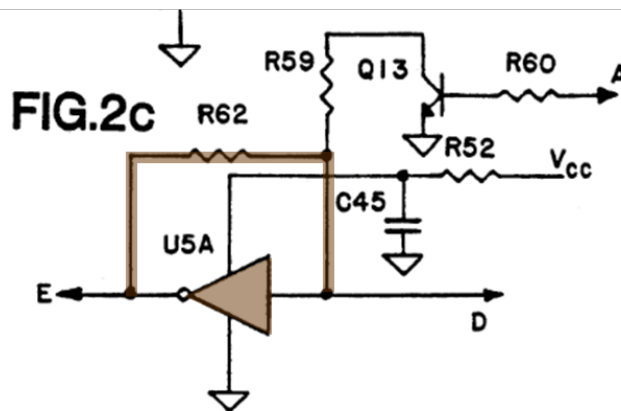
**Downey's Frequency Tripler  
(Mirror Image) (Fig. 2c) With  
Sedra's Switch (p. 909)**



**Sedra's Switch Within Inverter**



Pet., 55, 58.



Given the configuration of Downey (above) (including the feedback path with resistor R62 (brown path around the inverter)) and the transistor being driven by a sinusoidal signal), when inserted into Downey, Sedra's transistor would no longer function as a switch. Similar to the transistor in Downey, Sedra's transistor would function as an amplifier.

Transistors behave in different ways depending on the configuration of the circuit/system. Appx2380; Appx2352-2355; Appx2598-2609(¶¶ 121-152); Appx2630(¶196). ParkerVision's expert specifically explained that "in order to understand the operation of a circuit, one must view a circuit as a whole." Appx2606(¶ 144). Dr. Steer further explained:

One cannot simply look at *individual* components of the circuit. This is because the same components (e.g., transistors) used in different circuits can be used in *different* ways depending on a number of characteristics or parameters that can be varied.

*Id.* Yet, the PTAB failed to take this into account when performing its obviousness analysis. Instead, the PTAB addressed the disclosure of Sedra in isolation<sup>10</sup> and

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<sup>10</sup> It is important to note that the transistor in Sedra is not some specialized "switch." Rather, as ParkerVision explained in detail in its POR, the transistor in Sedra's logic inverter behaves like a switch because of the square-wave control

even discounted ParkerVision’s arguments that explain the implications of combining Downey with Sedra.

As explained above, just because a transistor operates as a switch in one circuit, does not mean that the transistor will operate as a switch in a differently configured circuit. The PTAB failed to recognize that combining Sedra with Downey alters the circuit configuration of Sedra, and thus how the transistor behaves in the circuit. That failure is legal error, and the Board has no evidence to support its conclusion.

Intel’s proposed combination, for example, includes a feedback path around Sedra’s transistor. As ParkerVision’s expert explained, the presence of negative feedback ensures that the transistor is always biased ON (always closed): “a CMOS inverter with appropriate feedback ensures that the *transistor operates its active region* (i.e., *it is always ON/conducting current*).” Appx2632(¶ 198); Appx2550 (“The power supply current is constant during dynamic operation since the inverter is biased for Class A operation.”). Similarly, under Intel’s proposed combination, Sedra’s transistor is driven by a sinusoidal input signal rather than of

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input it receives, how it is biased, and how it is configured in the circuit.

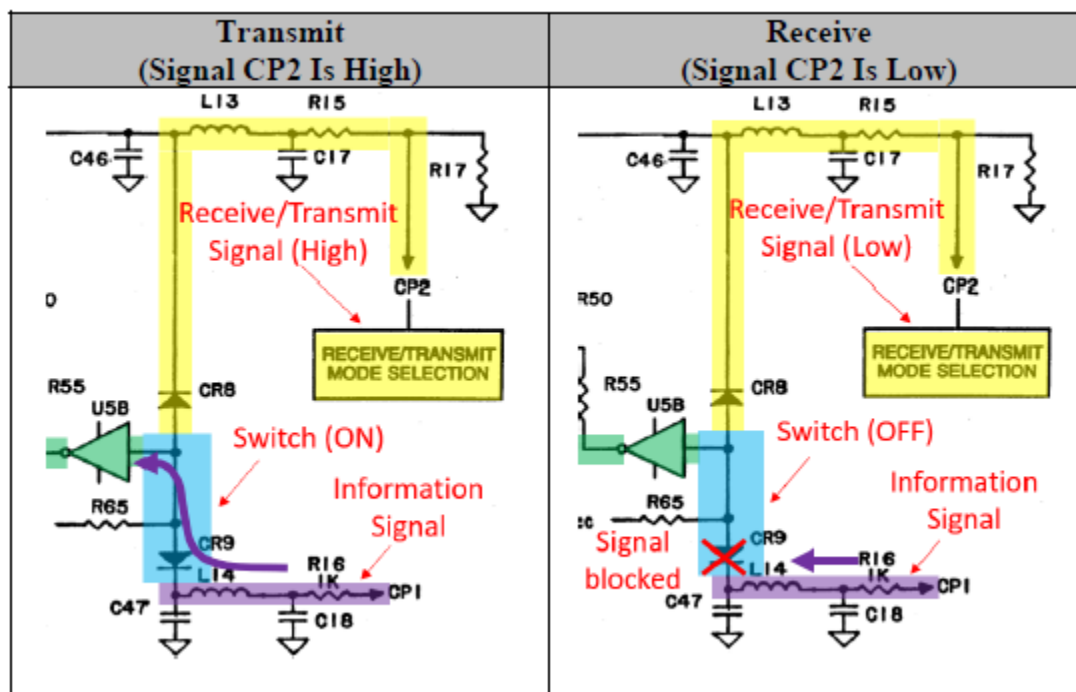
Appx2352-2355.

a square wave (as disclosed in Sedra). Because the transistor is appropriately biased, the sinusoidal input signal causes Sedra's transistor to operate in the saturation region and triode/linear region. Appx3537; Appx2603(¶¶ 137-138). As such, the Sera's transistor is always ON (closed), thus, operating as an amplifier. Appx3537-3538.

Accordingly, the PTAB erred in determining that the combination of Sedra's inverter and Downey's frequency-tripler circuit discloses "a *switch* configure to up-convert." The PTAB based its determination on finding a person of ordinary skill in the art would have had reasonable success in Intel's proposed combination because "Sedra provides a roadmap of how to construct an inverter to be used in the circuit of Downey." Appx42. But the PTAB failed to appreciate that Sedra's transistor, when constructed into the circuit of Downey, would not continue to operate as a switch. Sedra's transistor would operate as an amplifier. For this reason, the Court should reverse the obviousness determination.

**E. The PTAB erred in finding Intel's proposed combination discloses a "second switch".**

As shown below, Intel annotated Figure 2a of Downey and identified the "second switch" as diode CR9 (in the blue box). But Intel's annotated figures are wrong and do not show what is actually occurring in Downey's circuit. Diode CR9 (in the blue box) is not a "second switch" under the correct construction of a "switch."



Appx2705.

As discussed above, under the proper construction, a “switch” is an electronic device for opening and closing a circuit as dictated by an independent control input. The PTAB makes no attempt to determine whether diode CR9 (blue box) of Downey (identified as the “second switch”) meets the claimed “switch” limitation, as properly construed. More specifically, the PTAB is altogether silent as to whether diode CR9 opens/closes a circuit *as dictated by an independent control input*. If this Court agrees with Appellant’s claim construction of “switch,” the PTAB’s obviousness finding should be reversed. Alternatively, and at a

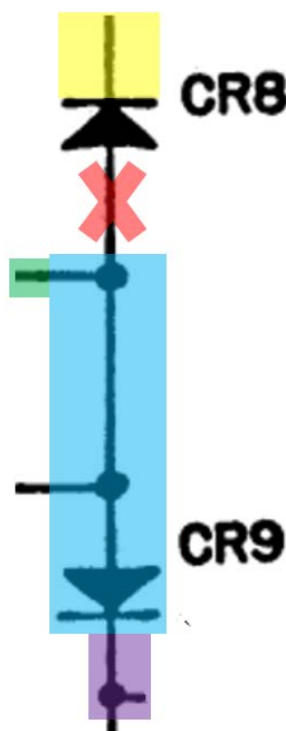
minimum, the Court should vacate and remand to the Board for a determination under the proper construction.

Intel addressed ParkerVision's "independent control input" language for the first time in its Reply, and asserted that "the input relating to receive/transmit signal CP2" is the "independent control input" for diode CR9. Appx2707. In particular, Intel argued that diode CR9 (shown with the blue box above) opens and closes a circuit based on the receive/transmit signal CP2 (shown with the yellow highlight in Fig. 2a above). Diode CR9, however, does not receive signal CP2 (signal CP2 can never reach diode CR9), and, thus, signal CP2 is not an input to diode CR9. Accordingly, signal CP2 cannot be an "independent control input" for diode CR9.

Specifically, Intel ignored that there is a diode CR8 above diode CR9. Diode CR8 has an arrow pointing upward (in the direction of pin CP2). Appx3544. As Intel's expert admitted, the diode arrow points in the direction of current flow. Appx3544-3445; Appx3593(149:21-25); Appx2346. And a POSITA understands that a diode allows the flow of current in only one direction. Appx3545; Appx2345. Given this configuration, when diode CR8 is conducting, current flows only through diode CR8 in the upward direction (i.e., towards the top of the diagram/towards pin CP2). Appx3545. When diode CR8 is non-conducting, no receive/transmit signal (yellow) from connector pin CP2 will not pass through

diode CR8. Appx3545-3546. Thus, in any mode of operation, the signal from CP2 will never pass through diode CR8, and certainly will never reach diode CR9. Appx3546. Thus, the yellow highlight labeled CP2 in Intel's annotated figures (above) is incorrect, and CP2 is not providing an independent control input to diode CR9.

Unlike Intel, ParkerVision provided an accurate representation of what is actually occurring in Downey's circuit (shown below).



Appx3547.

As shown above, diode CR8 (which Intel omits) prevents the signal (yellow) from CP2 from passing diode CR8 and, thus, the signal from CP2 will never appear where Intel has shown it. As such, since the signal from CP2 can never get

past diode CR8, it cannot be an independent control input into the highlighted blue box or diode CR9. Diode CR9 (or the blue box) is therefore not a “switch” under the correct construction of that term.

For the foregoing reasons, the PTAB’s determination should be reversed.

**F. The PTAB erred in finding Intel’s proposed combination discloses a “third switch.”**

Intel identified the “third switch” as transistor Q11 in the power amplifier circuit of Downey. But transistor Q11 acts as an amplifier to amplify a signal. As discussed above, an amplifier is not a switch. As such, the PTAB’s determination is an error and should be reversed.

**G. The PTAB’s decision is improperly based on theories not presented in the petition.**

The Board may not base its patentability decision on evidence and theories not presented in the Petition. *See Dell Inc. v. Accelaron, LLC*, 818 F.3d 1293, 1301 (Fed. Cir. 2016). Yet, that is what the Board did here. A patent owner must be given adequate notice of the unpatentability theories and evidence it faces, so that it may rebut those theories and evidence in its Patent Owner Response. *Id.*; *Belden, Inc. v. Berk-Tek LLC*, 805 F.3d 1064, 1080 (Fed. Cir. 2015). Indeed, 35 U.S.C. § 312(a)(3) requires that all of the Petitioner’s arguments and evidence must be presented “with particularity” in the petition. *Intelligent Bio-Systems, Inc. v. Illumina Cambridge, Ltd.*, 821 F.3d 1359, 1369 (Fed. Cir. 2016). This is because

“[u]nlike district court litigation—where parties have greater freedom to revise and develop their arguments over time and in response to newly discovered material—the expedited nature of IPRs bring with it an obligation for petitioners to make their case in their petition to institute.” *Id.*; see also *In re NuVasive, Inc.*, 841 F.3d 966, 969-73 (Fed. Cir. 2016). The Board, however, invalidated the challenged claims in view of Downey based on an untimely disclosed theory that was not presented in Intel’s Petition. The Board’s determination of unpatentability was therefore improper and should be reversed.

In particular, Intel’s Petition identifies a “third switch” as transistor Q11 in the power amplifier circuit of Downey and describes how that the supply current to transistor Q11 affects the operation of the transistor. Appx253-258. This is all that Intel said as to this claim element.

Then, for the first time in its Reply, Intel, introduced the concept of “switching amplifiers,” and asserted that Downey’s power amplifier circuit is actually a specific type of amplifier- a switching amplifier. Appx2711. In doing so, Intel submitted new evidence (Appx2867-3103, Appx3141-3177) and a supplemental declaration of Dr. van der Weide (Intel’s expert), newly describing how a switching amplifier can act as both a switch and amplifier at the same time.

A reply, however, “may only respond to arguments raised in the . . . patent owner response . . . .” 37 C.F.R. § 42.23(b). See *Intelligent Bio-Systems*, 821 F.3d

at 1366, 1369-70 (affirming the Board’s finding that the petitioner “ran afoul of § 42.23(b) by presenting a new argument for the first time in its reply brief”); *SAS Institute Inc. v. Iancu*, 138 S.Ct. 1348 (2018).

By arguing (and presenting never before disclosed evidence) that the power amplifier in Downey is a “switching amplifier,” Intel proceeded in a new direction with a new approach compared to the positions it took in the Petition. Based on Intel’s impermissible new theory, the Board determined that “transistor Q11 would act as a switching amplifier by opening and closing a circuit (the circuit between inductor L10 and resistor R51) based on the value of Signal F.” Appx56.

Intel had no basis whatsoever and zero record evidence in its Petition to show that transistor Q11 in Downey functions as a “switching amplifier.” For this reason alone, Intel’s Petition failed to meet its burden. In fact, the Petition was completely silent as to the concept of switching amplifiers. This lapse cannot be fixed in a reply. But this is what the Board allowed Intel to do.

Because Intel’s new theory and Dr. van der Weide’s analysis are untimely, the Board’s reliance on them is improper. Indeed, the Board should not have considered them at all. *Intelligent Bio-Systems*, 821 F.3d at 1366, 1369-70; *see also, SAS Institute Inc. v. Iancu*, 138 S.Ct. 1348 (2018). Accordingly, the Board’s determination of unpatentability should be reversed.

## **CONCLUSION**

For all of the reasons set forth above, the Board's decision and judgment must be reversed and vacated, and/or remanded.

January 17, 2023

Respectfully submitted,

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FORM 19. Certificate of Compliance with Type-Volume Limitations

Form 19  
July 2020

**UNITED STATES COURT OF APPEALS  
FOR THE FEDERAL CIRCUIT**

**CERTIFICATE OF COMPLIANCE WITH TYPE-VOLUME LIMITATIONS**

**Case Number:** 22-2173

**Short Case Caption:** PARKERVISION, INC. v. INTEL CORP.

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- ☐ the filing contains \_\_\_\_\_ pages / \_\_\_\_\_ words / \_\_\_\_\_ lines of text, which does not exceed the maximum authorized by this court's order (ECF No. \_\_\_\_\_).

Date: 01/17/2023

Signature: /s/ Ronald M. Daignault

Name: Ronald M. Daignault

## **ADDENDUM**

Trials@uspto.gov  
571-272-7822

Paper 33  
Date: June 30, 2022

UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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INTEL CORPORATION,  
Petitioner,

v.

PARKERVISION, INC.,  
Patent Owner.

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IPR2021-00346  
Patent 8,190,108 B2

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Before JONI Y. CHANG, BART A. GERSTENBLITH, and  
IFTIKHAR AHMED, *Administrative Patent Judges*.

AHMED, *Administrative Patent Judge*.

JUDGMENT  
Final Written Decision  
Determining All Challenged Claims Unpatentable  
*35 U.S.C. § 318(a)*

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## I. INTRODUCTION

Intel Corporation (“Petitioner”) requested an *inter partes* review of claims 1, 6–9, 12, and 17–20 (the “challenged claims”) of U.S. Patent No. 8,190,108 B2 (Ex. 1001, “the ’108 patent”). Paper 3 (“Petition” or “Pet.”). ParkerVision, Inc. (“Patent Owner”) filed a Preliminary Response. Paper 7. Applying the standard set forth in 35 U.S.C. § 314(a), we instituted an *inter partes* review of the challenged claims. Paper 12 (“Inst. Dec.”).

After institution, Patent Owner filed a Patent Owner Response (Paper 17, “PO Resp.”), Petitioner filed a Reply to Patent Owner’s Response (Paper 23, “Pet. Reply”), and Patent Owner filed a Sur-reply (Paper 28, “PO Sur-reply”). An oral hearing was held on April 26, 2022, and a copy of the transcript was entered in the record. Paper 32 (“Tr.”).

We have jurisdiction pursuant to 35 U.S.C. § 6. This Decision is a Final Written Decision under 35 U.S.C. § 318(a) and 37 C.F.R. § 42.73 as to the patentability of the claims on which we instituted trial. To prevail, Petitioner must prove unpatentability by a preponderance of the evidence. *See* 35 U.S.C. § 316(e) (2018); 37 C.F.R. § 42.1(d) (2020). Having reviewed the arguments and the supporting evidence, we determine that Petitioner has shown, by a preponderance of the evidence, that claims 1, 6–9, 12, and 17–20 of the ’108 patent are unpatentable.

## II. BACKGROUND

### A. *Real Parties-in-Interest*

Petitioner identifies itself, Intel Corporation, as the real party-in-interest. Pet. 1, 8. Patent Owner identifies itself, ParkerVision, Inc., as the real party-in-interest. Paper 5, 1.

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*B. Related Matters*

According to the parties, the '108 patent has been asserted in *ParkerVision, Inc. v. Intel Corp.*, No. 6:20-cv-00562-ADA (W.D. Tex.). Pet. 86; Paper 5, 1. Petitioner also identifies as related matters IPR2020-01265 and IPR2020-01302, challenging U.S. Patent Nos. 7,110,444 and 7,539,474, respectively, which are asserted in *ParkerVision, Inc. v. Intel Corp.*, No. 6:20-cv-00108-ADA (W.D. Tex.). Pet. 8.

*C. The '108 Patent (Ex. 1001)*

The '108 patent, titled “Method and System for Frequency Up-Conversion,” was filed on April 26, 2011, and claims priority to U.S. Patent Application No. 09/176,154, filed on October 21, 1998. Ex. 1001, codes (22), (54), (60). The '108 patent issued on May 29, 2012. *Id.* at code (45). The '108 patent describes that communication systems transmit information by modulating a carrier signal, where the carrier signal typically has a higher frequency than a baseband information signal. *See id.* at 1:44–51. The '108 patent relates to “up-convert[ing] a signal from a lower frequency to a higher frequency.” *Id.* at 1:66–67. In particular, “the invention accepts an information signal at a baseband frequency and transmits a modulated signal at a frequency higher than the baseband frequency.” *Id.* at 2:5–8.

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Figure 12 of the '108 patent illustrates a structural block diagram of a transmitter according to a frequency modulation (FM) embodiment (*id.* at 3:11–13, 18:63–65), and is reproduced below.

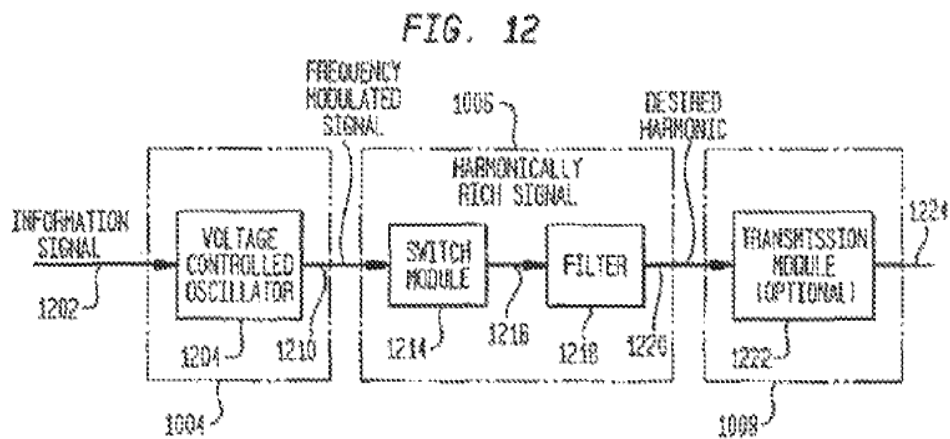


Figure 12 shows that the transmitter routes an input information signal to voltage controlled oscillator 1204, which generates and modulates oscillating frequency modulated signal 1210. *Id.* at 19:21–26. Switch module 1214 then generates “harmonically rich signal 1216 with a continuous and periodic waveform.” *Id.* at 19:26–29. Next, filter 1218 filters out unwanted harmonics and outputs a signal at a desired harmonic frequency, which transmission module 1222 prepares for transmission. *Id.* at 19:37–43.

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Figure 28A of the '108 patent illustrates a switch module (*id.* at 3:52–53, 31:59–64), and is reproduced below.

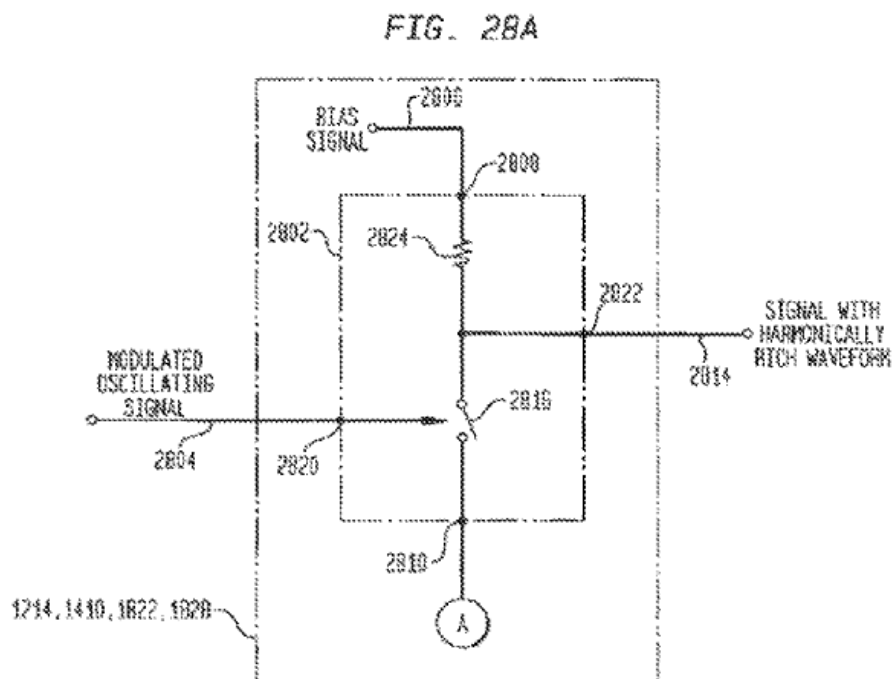
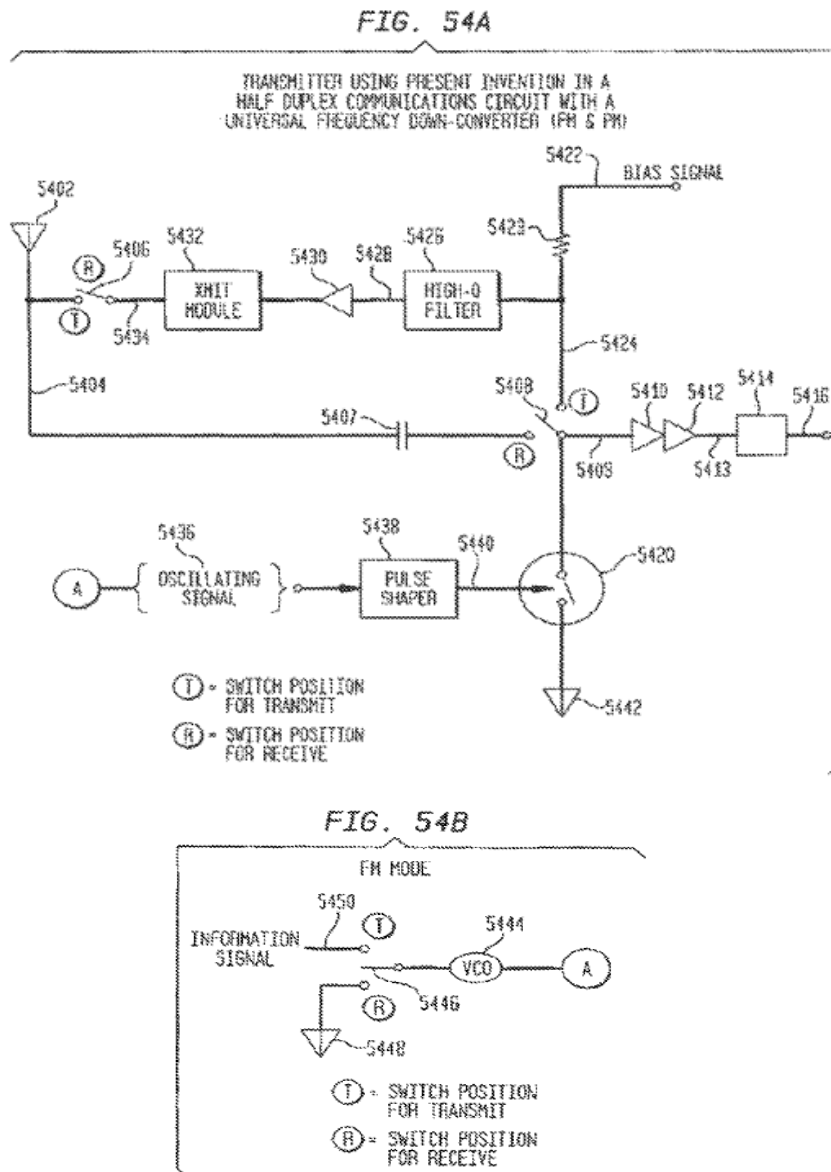


Figure 28A shows an implementation of switch module 1214 of Figure 12. *Id.* at 31:59–64. “A bias signal 2806 is gated as a result of the application of a modulated oscillating signal 2804, and a signal with a harmonically rich waveform 2814 is created.” *Id.* at 32:9–11. “The bias signal 2806 is generally a fixed voltage,” and “[t]he modulated oscillating signal 2804 can be frequency modulated, phase modulated, or any other modulation scheme.” *Id.* at 32:11–14. Harmonically rich signal 2814 “is a continuous and periodic waveform that is modulated substantially the same as the modulated oscillating signal 2804.” *Id.* at 32:35–38.

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Figures 54A and 54B of the '108 patent illustrate a transceiver circuit (*id.* at 4:52–55, 54:30–34), and are reproduced below.



Figures 54A and 54B show an implementation of FM modulation mode, where the transceiver uses antenna 5402, oscillator 5444, pulse shaper 5438, and switch 5420 to transmit and to receive. *Id.* at 54:34–39. When the transceiver is performing the transmit function, the Receive/Transmit (R/T)

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switches 5406, 5408, and 5446 are in the Transmit (T) position, with an incoming information signal 5450 connected by switch 5446 to VCO 5444 to create a frequency modulated oscillating signal 5436. *Id.* at 55:5–9, Fig. 54B. The oscillating signal is then routed through pulse shaper 5438 to create a string of pulses 5440 which in turn cause switch 5420 to open and close, resulting in “a harmonically rich signal 5424.” *Id.* at 55:12–17, Fig. 54A. That signal is filtered, amplified, and routed to transmission module 5432, which outputs a transmission signal 5434 to antenna 5402, connected to another R/T switch 5406. *Id.* at 55:17–25, Fig. 54A.

*D. Challenged Claims*

Petitioner challenges claims 1, 6–9, 12, and 17–20, of which claims 1 and 12 are independent. Pet. 10. Claims 6–9 depend from claim 1 and claims 17–20 depend from claim 12. *Id.* Claim 1 is reproduced below.

1. [1Preamble] A frequency conversion module, comprising:

[1A] a first switch configured to up-convert a signal based on a control signal and a bias signal,

[1B] wherein said signal are routed to said frequency conversion module via a second switch, and

[1C] wherein said signal is transmitted by an antenna connected to a third switch.

Ex. 1001, 65:49–55 (Petitioner’s annotations added).

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*E. Prior Art and Instituted Grounds of Unpatentability*

We instituted trial based on the following grounds of unpatentability:

Claims Challenged	35 U.S.C. § <sup>1</sup>	References
1, 12	103(a)	Downey, <sup>2</sup> Sedra <sup>3</sup>
6–9, 17–20	103(a)	Downey, Sedra, Hahnel <sup>4</sup>

Inst. Dec. 37. Petitioner supports its arguments with declaration testimony of Dr. Daniel van der Weide. Exs. 1002, 1030. Patent Owner supports its arguments with a Declaration by Dr. Michael Steer. Ex. 2022.

### III. ANALYSIS

*A. Principles of Law*

“In an [*inter partes* review], the petitioner has the burden from the onset to show with particularity why the patent it challenges is unpatentable.” *Harmonic Inc. v. Avid Tech., Inc.*, 815 F.3d 1356, 1363 (Fed. Cir. 2016) (citing 35 U.S.C. § 312(a)(3) (requiring *inter partes* review petitions to identify “with particularity . . . the evidence that supports the grounds for the challenge to each claim”)). This burden of persuasion never shifts to Patent Owner. *See Dynamic Drinkware, LLC v. Nat’l Graphics, Inc.*, 800 F.3d 1375, 1378 (Fed. Cir. 2015) (discussing the burden of proof in *inter partes* review).

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<sup>1</sup> Because the challenged claims of the ’108 patent have an effective filing date before March 16, 2013 (*see* Ex. 1001, codes (22), (60)), patentability is governed by the pre-AIA version of 35 U.S.C. § 103.

<sup>2</sup> U.S. Patent No. 5,239,686, issued Aug. 24, 1993 (Ex. 1003, “Downey”).

<sup>3</sup> ADEL S. SEDRA ET AL., MICROELECTRONIC CIRCUITS (3rd ed. 1991) (Ex. 1004, “Sedra”).

<sup>4</sup> U.S. Patent No. 2,730,624, issued Jan. 10, 1956 (Ex. 1005, “Hahnel”).

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As set forth in 35 U.S.C. § 103(a),

[a] patent may not be obtained . . . if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

The question of obviousness is resolved on the basis of underlying factual determinations including: (1) the scope and content of the prior art; (2) any differences between the claimed subject matter and the prior art; (3) the level of ordinary skill in the art; and (4) when in evidence, objective evidence of nonobviousness.<sup>5</sup> *Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966). An obviousness analysis “need not seek out precise teachings directed to the specific subject matter of the challenged claim, for a court can take account of the inferences and creative steps that a person of ordinary skill in the art would employ.” *KSR Int’l Co. v. Teleflex Inc.*, 550 U.S. 398, 418 (2007). However, Petitioner cannot satisfy its burden of proving obviousness by employing “mere conclusory statements.” *In re Magnum Oil Tools Int’l, Ltd.*, 829 F.3d 1364, 1380 (Fed. Cir. 2016). Instead, Petitioner must articulate a reason why a person of ordinary skill in the art would have combined the prior art references. *In re NuVasive*, 842 F.3d 1376, 1382 (Fed. Cir. 2016).

*B. Level of Ordinary Skill in the Art*

We review Petitioner’s asserted obviousness grounds in view of the understanding of a person of ordinary skill in the art at the time of the invention. *Graham*, 383 U.S. at 17. Petitioner contends that a person of ordinary skill in the art “would have had at least a bachelor’s degree in

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<sup>5</sup> Neither party presents evidence of objective indicia of nonobviousness.

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electrical engineering or a related subject and two or more years of experience in the field of radio frequency circuit design.” Pet. 40 (citing Ex. 1002 ¶ 29). Patent Owner contends that a person of ordinary skill in the art “would have: (a) a Bachelor of Science degree in electrical or computer engineering (or a related academic field), and at least two (2) additional years of experience in the design and development of radio frequency circuits and/or systems, or (b) at least five (5) years of experience and training in the design and development of radio frequency circuits and/or systems.” PO Resp. 5 (citing Ex. 2022 ¶ 20). We determine that the two proposed levels are closely aligned and are consistent with the ’108 patent and the asserted prior art.<sup>6</sup> See *Okajima v. Bourdeau*, 261 F.3d 1350, 1355 (Fed. Cir. 2001); *In re GPAC Inc.*, 57 F.3d 1573, 1579 (Fed. Cir. 1995); *In re Oelrich*, 579 F.2d 86, 91 (CCPA 1978). We adopt the following level in determining the patentability of the challenged claims: a person of ordinary skill in the art would have had a bachelor’s degree in electrical or computer engineering, or a related subject, and two years of experience in the field of radio frequency circuit design and development.

### C. Claim Construction

In this *inter partes* review, claims are construed using the same claim construction standard that would be used to construe the claims in a civil action under 35 U.S.C. § 282(b). See 37 C.F.R. § 42.100(b) (2020). The claim construction standard includes construing claims in accordance with the ordinary and customary meaning of such claims as understood by one of ordinary skill in the art at the time of the invention. See *id.*; *Phillips v. AWH*

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<sup>6</sup> Neither party asserts that the minor difference in the proposed levels of ordinary skill in the art makes a substantive difference in this proceeding.

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*Corp.*, 415 F.3d 1303, 1312–14 (Fed. Cir. 2005) (en banc). In construing claims in accordance with their ordinary and customary meaning, we take into account the specification and prosecution history. *Phillips*, 415 F.3d at 1315–17.

If the specification “reveal[s] a special definition given to a claim term by the patentee that differs from the meaning it would otherwise possess[,] . . . the inventor’s lexicography governs.” *Phillips*, 415 F.3d at 1316 (citing *CCS Fitness, Inc. v. Brunswick Corp.*, 288 F.3d 1359, 1366 (Fed. Cir. 2002)). Another exception to the general rule that claims are given their ordinary and customary meaning is “when the patentee disavows the full scope of a claim term either in the specification or during prosecution.” *Uship Intellectual Props., LLC v. United States*, 714 F.3d 1311, 1313 (Fed. Cir. 2013) (quoting *Thorner v. Sony Computer Entm’t Am., LLC*, 669 F.3d 1362, 1365 (Fed. Cir. 2012)).

Additionally, only terms that are in controversy need to be construed, and those need be construed only to the extent necessary to resolve the controversy. See *Vivid Techs., Inc. v. Am. Sci. & Eng’g, Inc.*, 200 F.3d 795, 803 (Fed. Cir. 1999) (holding that “only those terms need be construed that are in controversy, and only to the extent necessary to resolve the controversy”); *Nidec Motor Corp. v. Zhongshan Broad Ocean Motor Co.*, 868 F.3d 1013, 1017 (Fed. Cir. 2017) (citing *Vivid Techs.* in the context of an *inter partes* review).

In the Institution Decision, we did not construe any claim terms expressly because none of the terms were in dispute. Inst. Dec. 10–11. In the briefing following institution, Patent Owner proposed a construction for the terms “switch” and “third switch,” see, e.g., PO Resp. 31–34, and it

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became clear that the parties dispute the meaning of the term “switch,” and construing that term is important to address the issues presented in this proceeding. Accordingly, we address the parties’ arguments and proposed constructions.

*1. The Parties’ Arguments*

In the Petition, Petitioner does not propose a construction for “switch,” but does assert that “[t]here is no need to construe the[] term[] for purposes of this IPR because . . . the prior art discloses the term[] under either Petitioner’s or Patent Owner’s proposed interpretations.” Pet. 29–30, n.2 (citing Ex. 1002 ¶¶ 62–63).

In the Patent Owner Response, Patent Owner notes that the U.S. District Court for the Western District of Texas (“Texas Court”) construed “switch” in the related litigation as “an electronic device for opening and closing a circuit as dictated by an independent control input.” PO Resp. 31; *see also id.* at 3–4 (citing Ex. 2011 (Document 61, Claim Construction Order), 2). Patent Owner contends that the difference between the parties’ constructions at the district court was the additional language proposed by Patent Owner, “as dictated by an independent control input,” which the district court adopted. *Id.* at 32 (citing Ex. 2011, 2). Patent Owner contends that “[a]ccording to the Specification, a control signal is transmitted to a switch from a source external to the switch, thereby making opening and closing a circuit dictated by an independent control input.” *Id.* at 32–34 (citing Ex. 1001, 41:9–14, 55:12–14, Fig. 54A). Patent Owner argues that “each disclosed embodiment in the ’108 patent depicts a switch with an independent control input (i.e., an input, an output, and a control).” *Id.* at 34 (citing Ex. 1001, 7:57–63; Figs. 28A, 29A, 30A, 31A, 32A, 33A, 54A,

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57A–C). Patent Owner argues that we should adopt the Texas Court’s construction for the “switch” terms. *Id.*

Patent Owner notes that the U.S. District Court for the Middle District of Florida, Orlando Division (“Orlando Court”) also construed the term “switch” for claims of related U.S. Patent No. 6,091,940 (“the ’940 patent”), and also adopted Patent Owner’s proposed construction as a “device with an input and output that can take two states, open and closed, as dictated by an independent control input.” *Id.* (citing Ex. 2013 (Document 381, Claim Construction Order), 32).

Petitioner contests Patent Owner’s characterization of the Specification of the ’108 patent as well as Patent Owner’s construction of “switch.” *See* Pet. Reply 4–7. Petitioner contends that the term “switch” has a readily understood meaning in the art “as an electronic device for opening and closing a circuit.” *Id.* at 5 (citing Ex. 1036 (an IEEE Dictionary), 906; Ex. 1037 (a Webster Dictionary), 1354). Petitioner contends that the ’108 patent uses “switch” consistently with its widely understood meaning, referring to switches “opening and closing” and indicating that some switches might not be controlled by an electronic signal. *Id.* (citing Ex. 1001, 54:61–63, 7:60–61). In fact, Petitioner argues, nothing in the ’108 patent even refers to an “independent control input” let alone limits a switch to opening and closing as dictated by an independent control. *Id.* Petitioner points out that Patent Owner previously agreed to the same construction proposed by Petitioner here in a different prior litigation in the U.S. District Court for the Middle District of Florida, Jacksonville Division (“Jacksonville Court”) involving another related patent, U.S. Patent 9,118,528 (“the ’528 patent”). *Id.* (citing Ex. 1039 (Document 86-1, Joint-

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Claim-Construction-Chart, 2 (“Agreed Upon Constructions”))). Petitioner further contends that no construction of “third switch” is necessary, but if we were to construe the term, we should reject Patent Owner’s “independent control input” language for the same reasons as argued for the term “switch.” *Id.* at 7.

In its Sur-reply, Patent Owner responds that “both the Orlando and Texas Courts have already considered and rejected the same arguments that [Petitioner] makes here seeking to exclude ‘as dictated by an independent control input.’” PO Sur-reply 2. Patent Owner additionally points out that more recently, the Texas Court appointed a Special Master to address claim construction in the related litigation and that the Special Master recommended construing “switch” consistent with the Texas Court’s prior constructions. *Id.* at 2 n.1 (citing *ParkerVision, Inc. v. TCL Indus. Holdings Co.*, No. 6:20-cv-00945-ADA, at Dkt. No. 49 (W.D. Tex. Oct. 29, 2021)). Patent Owner argues that *each* disclosed embodiment in the ’108 patent depicts a switch with an input, an output, and an independent control input. *Id.* at 3 (citing Ex. 1001, Figs. 28A, 29A, 30A, 31A, 32A, 33A, 54A, 57A–C). Patent Owner further contends that the passage of the ’108 patent Specification that Petitioner relies on has already been considered by the Orlando Court. *Id.* at 2–5 (citing Ex. 1001, 7:60–61; Ex. 2013, 30–32). Moreover, Patent Owner argues, reading Petitioner’s cited passage in context demonstrates that rather than suggesting that a switch is sometimes not controlled by an independent control input, that passage distinguishes the switch typically being controlled by an electronic signal as opposed to mechanical, electrical, optical or some other manner. *Id.* at 5. Patent Owner also asks us to ignore that it previously agreed, in the Jacksonville litigation,

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to the same construction proposed by Petitioner here because the Orlando Court’s construction of the same term “came *after* this agreement,” and “a district court’s construction trumps any agreement the parties made in litigation.”<sup>7</sup> *Id.* As for the term “third switch,” Patent Owner contends that the term “is straight-forward and does not require a construction other than ‘switch.’” *Id.* at 6.

Patent Owner also argues that it would be improper to rely on Petitioner’s extrinsic evidence in construing the “switch” terms because the extrinsic evidence is inconsistent with the disclosure of the ’108 patent. PO Sur-reply 4.

## 2. *Analysis*

We begin by noting that the Texas Court has construed the terms “switch” and “third switch” recited in claim 1 of the ’108 patent. *See* Ex. 1026, 5. As set forth in 37 C.F.R. § 42.100(b), we consider “[a]ny prior claim construction determination concerning a term of the claim in a civil action . . . that is timely made of record.” We have done so to the extent possible on the record before us. In particular, the district court’s claim construction is set forth in a chart format without providing the benefit of the court’s analysis as to how that construction was determined. The lack of explanation is particularly of note here because the district court did not expressly address the parties’ dispute as to whether a diode is a type of switch with an independent control input—a dispute similar to the one

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<sup>7</sup> The agreed construction was filed in the Jacksonville Court on January 5, 2018 and relates to the “switch” term in the ’528 patent, while the Orlando Court entered its claim construction order on April 29, 2020 and construes the “switch” and “switch module” terms in the related ’940 patent. *See* Ex. 1039, 2; Ex. 2013, 58.

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before us. *See* Ex. 1040, 12 (discussing the parties’ argument to the court). Moreover, the term “third switch” is used differently in claim 1 as compared to claim 12 of the ’108 patent. *See* Ex. 1001, 65:54–55, 66:37–39 (claim 1 recites a third switch connected to an antenna while claim 12 recites a third switch used to up-convert the signal). The court, however, construed the terms to have their plain and ordinary meaning, and then decided that the plain and ordinary meaning of “switch” is “an electronic device for opening and closing a circuit as dictated by an independent control input.” As reflected in the chart below, reproduced from the chart included in the district court’s decision, the court’s decision recites the two parties’ proposed constructions and the court’s final construction of the terms.

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<b>Term</b>	<b>Patent Owner's Proposed Construction</b>	<b>Petitioner's Proposed Construction</b>	<b>District Court's Final Construction</b>
"switch"  '108 patent, claim 1 <sup>8</sup>	"an electronic device for opening and closing a circuit <i>as dictated by an independent control input</i> "	"an electronic device for opening and closing a circuit"	Plain-and-ordinary meaning wherein the plain-and-ordinary meaning is "an electronic device for opening and closing a circuit <i>as dictated by an independent control input</i> "
"third switch"  '108 patent, claim 1	Plain and ordinary meaning, or "switch" as construed by the Court in Case No. 6:20-cv-108	"a switch controlling whether the antenna transmits said signal"	"Switch": Plain-and-ordinary meaning wherein the plain-and-ordinary meaning is "an electronic device for opening and closing a circuit <i>as dictated by an independent control input</i> "

See Ex. 1026, 5, 15 (emphases added).<sup>9</sup> We are therefore deprived of the court's reasoned analysis that resulted in the court's construction of the term "switch" and "third switch."<sup>10</sup>

The Orlando Court's decision in adopting Patent Owner's proposed construction for claims of the '940 patent is based primarily on the fact that the defendant in that case, Qualcomm Inc. ("Qualcomm"), had previously

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<sup>8</sup> The court's decision lists claims of other patents in this portion of the chart that are not at issue in this proceeding and therefore have been omitted from the chart above.

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“agreed with the construction of ‘switch/switch module’ . . . advanced by [Patent Owner].” Ex. 2013, 31. The court’s analysis in arriving at its construction is provided below:

Qualcomm’s current argument is largely limited to their reference to the ’940 patent at 7:54–60, where the patent provides that “typically” a switch is controlled by an electronic or electrical input. The Court agrees with ParkerVision, however, that the embodiments and teachings of the patent as a whole support Plaintiff’s construction of “switch/switching module.”

Ex. 2013, 32.<sup>11</sup> The Orlando Court adopted Patent Owner’s proposed construction in that case as a “device with an input and output that can take two states, open and closed, as dictated by an independent control input.”

*Id.* Aside from the court’s statement above agreeing with Patent Owner that the teachings of the patent support Patent Owner’s construction, we do not

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<sup>9</sup> The Special Master’s recommendation to the Texas Court that Patent Owner relies on also includes nothing more than the claim construction set forth in a chart format similar to the district court’s decision. *See ParkerVision, Inc. v. TCL Indus. Holdings Co.*, No. 6:20-cv-00945-ADA, Dkt. No. 49 (W.D. Tex. Oct. 29, 2021)).

<sup>10</sup> At the oral hearing, Patent Owner noted that “[t]here were several claim construction hearings,” but did not point us to any reasoning that the court may have provided at any of those hearings. *See* Tr. 35:8–16. The transcripts available on the docket in the Texas cases do not address the construction of the term “switch.” *See generally ParkerVision, Inc. v. Intel Corp.*, No. 6:20-cv-00108-ADA, Dkt. 77 (W.D. Tex. Jan. 29, 2021); *ParkerVision, Inc. v. Intel Corp.*, No. 6:20-cv-00562-ADA, Dkts. 57, 63 (W.D. Tex. June 27, 2021, Aug. 8, 2021).

<sup>11</sup> Although Patent Owner argues that “the Orlando Court provided a detailed written opinion,” most of that opinion lays out the parties’ arguments to the court, the procedural history of the claim construction dispute, the Board’s prior construction of the claim terms, and the claim construction standard employed by the Board in the *inter partes* review. *See* Ex. 2013, 24–32.

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have before us the court’s reasoned analysis that may have resulted in the court’s decision to adopt that construction. We do, however, consider both courts’ construction as we analyze the meaning of “switch” based on the complete record before us. *See* 37 C.F.R. § 42.100(b).

As part of its discussion, the Orlando Court noted that the Board previously construed the terms “switch” and “switch module” in claims of the ’940 patent to mean a “device with an input and output that can take two states, open and closed.” Ex. 2013, 25 (citing *Qualcomm Inc. v. ParkerVision, Inc.*, IPR2015-01829, Paper 30 at 7 (PTAB Mar. 7, 2017)). In that *inter partes* review, Patent Owner agreed with the Board’s construction from the institution decision. *See* IPR2015-01829, Paper 30 at 7. As the Orlando Court pointed out, the Board’s construction was based on the broadest reasonable interpretation of the claims, and Patent Owner did not appeal the Board’s construction to the U.S. Court of Appeals for the Federal Circuit. Ex. 2013, 25 (citing *ParkerVision v. Qualcomm*, 903 F.3d 1354, 1358 (Fed. Cir. 2018)).

As reflected in the arguments above, Patent Owner’s proposed construction in this proceeding matches the Texas Court’s final construction in the related litigation. Petitioner too presents the same construction here that it proposed in the related litigation. The parties’ proposed constructions in this proceeding are reflected in the chart below.

<b>Term</b>	<b>Patent Owner’s Proposed Construction</b>	<b>Petitioner’s Proposed Construction</b>
“switch”	“an electronic device for opening and closing a circuit as dictated by an independent control input”	“an electronic device for opening and closing a circuit”

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*See, e.g.*, PO Resp. 31 (emphasis altered), 34; Pet. Reply 5. The parties make the same arguments regarding the term “third switch.” PO Resp. 31; Pet. Reply 7.

We begin with the language of claim 1, which does not expressly require an independent control input for every switch. Claim 1, as reproduced above, is directed to “[a] frequency conversion module, comprising: a first switch configured to up-convert a signal based on a control signal and a bias signal.” Ex. 1001, 65:49–51. Claim 1, therefore, recites a *control signal* that up-converts another signal by controlling the first switch that is configured to perform the up-conversion. *Id.* On the other hand, claim 1 does not recite a control signal in relation to the operation performed by the second switch and the third switch. *Id.* at 65:52–53. The same is true for claim 12, which instead recites that the third switch is used to up-convert a signal based on a *control signal*. *Id.* at 66:31–39. The claims therefore suggest that the patentees understood how to recite a control signal to the switch when the patentees intended to do so, but did not add an independent control input requirement to any of the switches.

We now turn to the Specification of the ’108 patent. The Specification includes a section titled “Terminology.” Ex. 1001, 7:22–9:46. This section provides lexicographic definitions of numerous terms used in the ’108 patent. Among the terms defined therein is the phrase “control a switch”:

Control a switch: Causing a switch to open and close. The switch may be, without limitation, mechanical, electrical, electronic, optical, etc., or any combination thereof. Typically, it is controlled by an electrical or electronic input. If the switch is

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controlled by an electronic signal, it is typically a different signal than the signals connected to either terminal of the switch.

*Id.* at 7:57–64. We find this paragraph of critical importance to understanding the patentees’ intended meaning of the term “switch” and walk through each sentence.

The first sentence of this paragraph defines the phrase “[c]ontrol a switch” as “[c]ausing a switch to open and close.” This aspect is not in dispute.

The second sentence of this paragraph provides examples of different types of switches, expressly states that the examples are “without limitation,” and states that “[t]he switch may be” “mechanical, electrical, electronic, optical, etc. or any combination thereof.” This aspect also is not in dispute as the parties agree that, in the context of the claims, the switch is an “electronic device.”

The third sentence refers back to “the switch” just described in the second sentence using the pronoun “it” and specifically states that “[t]ypically” the type of input that may control the switch is “an electrical or electronic input.” This sentence is important at least because the patentees chose to describe these control inputs as “typically.” The use of “typically,” in this context, is non-limiting. In other words, the ’108 patent expressly leaves open the option that the described switch may be controlled with an input that is not electrical or electronic.

The fourth, and final, sentence of this paragraph is critical. It specifically states that “[i]f the switch is controlled by an electronic signal, it is typically a different signal than the signals connected to either terminal of the switch.” This sentence is significant for several reasons. First, by stating “*if* the switch is controlled by an electronic signal” (emphasis added),

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the Specification reaffirms that the switch *may* be controlled by an input that is not an electronic signal. Second, reading the sentence as a whole, it states that “[i]f the switch is controlled by an electronic signal, it is *typically* a different signal than the signals connected to either terminal of the switch” (emphasis added). To clarify, a signal that is different than the signals connected to either terminal of the switch is what the parties refer to as “an independent control signal.” Thus, the fourth sentence, in the context of the parties’ dispute, means that *if* the switch is controlled by an electronic signal, it is *typically* an independent control signal. The same meaning of “typically” applies here, i.e., it is non-limiting. Thus, if the first part of the sentence that provides the conditional clause (if) is met, i.e., the switch is controlled by an electronic signal, the electronic signal is *not always* an independent control signal because typically does not require always.

Putting the discussion above into context, particularly in comparison to the construction advocated by Patent Owner, it is important to recognize that the lexicographic definition *does not require* a switch to be “dictated by an independent control input” because the definition specifically says that if the switch is controlled by an electronic control signal it is *typically* a different signal (i.e., an independent signal). Thus, Patent Owner’s proposed construction seeks to *limit* the term “switch” to what is expressly stated in the Specification as *typical*.

Patent Owner argues that the fourth sentence of the definition “merely refers to the switch typically being controlled by an electronic signal as *opposed to mechanical, electrical, optical or some other manner.*” PO Sur-reply 5. According to Patent Owner, “[t]he passage does not say that the switch is sometimes not controlled by an independent control input. The

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fact remains that an independent control input is always controlling the switch.” *Id.* We agree with Patent Owner that the passage does not *expressly* say “the switch is sometimes not controlled by an independent control input.” But, that is not what Petitioner contends nor does it resolve the issue before us. As noted above, the passage states that if the switch is controlled by an electronic signal it is typically a different signal (i.e., an independent signal). That is, that the control input need not *always* be “independent,” in the manner that Patent Owner’s proposed construction mandates. *See Praxair, Inc. v. ATMI, Inc.*, 543 F.3d 1306, 1323 (Fed. Cir. 2008) (“the word ‘typically’ . . . impl[ies] that the passage describes only the most common embodiment rather than the full scope of the invention”). If the patentees wanted to limit the term “switch” to require an independent control input, the description provided in the “terminology” section of the Specification would have made that clear.<sup>12</sup> Ex. 1001, 7:57. For the reasons explained above, however, the description does not. Therefore, we do not agree with Patent Owner that “switch” should be *limited* to require “an independent control input.”

Patent Owner further argues that *each* disclosed embodiment in the ’108 patent depicts a switch with an input, an output, and an independent control input. PO Sur-reply 3 (citing Ex. 1001, Figs. 28A, 29A, 30A, 31A, 32A, 33A, 54A, 57A–C). But the ’108 patent Specification “does not describe the invention as limited to embodiments having” an independent

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<sup>12</sup> Additionally, the terminology section states that “[e]ach description in this section is provided for illustrative and convenience purposes only, and is *not limiting*.” Ex. 1001, 7:24–25 (emphasis added). Yet, Patent Owner urges us to limit the “switch” even beyond the definition and description provided in the Specification. We decline to do so.

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control input. *See Liebel-Flarsheim Co. v. Medrad, Inc.*, 358 F.3d 898, 906–08 (Fed. Cir. 2004) (rejecting the argument that when “the subject matter claimed in the patent-in-suit is the only subject matter described . . . that subject matter is the invention, and not simply a ‘preferred embodiment’ of a broader invention”); *i4i Ltd. v. Microsoft Corp.*, 598 F.3d 831, 843–44 (Fed. Cir. 2010) (“[A] claim is not limited to the embodiments described in the specification unless the patentee has demonstrated a clear intention to limit the claim’s scope with words or expressions of manifest exclusion or restriction.”). In fact, the ’108 patent Specification does not even refer to an “independent control input,” and discusses switches only as opening and closing. *See, e.g.*, Ex. 1001, 54:61–63 (“As a result of the switch opening and closing, a down converted signal 5409 is generated.”). Given the ’108 patent’s description of how a switch is controlled (*id.* at 7:57–64), we find no “clear intention to limit the claim’s scope.”<sup>13</sup> *See i4i*, 598 F.3d at 843–44.

Turning to extrinsic evidence, we note that Dr. Steer agrees with Patent Owner’s proposed construction, whereas Dr. van der Weide does not offer an opinion on the meaning of the term “switch.” Specifically, Dr. Steer testifies that the Texas Court’s “construction is correct and accurately captures the meaning of ‘switch’ as understood by a [person of ordinary skill in the art (‘POSITA’)].” *See* Ex. 2022 ¶ 166. Although we have considered Dr. Steer’s testimony, we find it “less significant than the intrinsic record in determining the legally operative meaning of” the term

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<sup>13</sup> Patent Owner has not pointed us to any aspect of the prosecution history of the ’108 patent that supports interpreting the claim term as proposed by Patent Owner. *See* PO Resp. 31–34; PO Sur-reply 1–6.

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“switch.” *Phillips*, 415 F.3d at 1317 (internal quotations and citations omitted). In particular, we are cognizant of the Federal Circuit’s guidance that we “should discount any expert testimony that is clearly at odds with the claim construction mandated by . . . the written description.” *Id.* at 1318 (internal quotation and citation omitted). In this instance, we find that Dr. Steer’s testimony is clearly at odds with the description of switch provided in the ’108 patent because that description does not require that the operation of a switch *always* be “dictated by an independent control input.” Moreover, other extrinsic evidence, such as dictionary definitions offered by Petitioner, supports that the widely understood meaning of the term switch was a device for opening and closing a circuit. *See* Pet. Reply 5 (citing Ex. 1036 (IEEE Standard Dictionary of Electrical and Electronics Terms (3d ed. 1984)) (defining “switch” as “[a] device designed to close or open, or both, one or more electric circuits”)); Ex. 1037 (Webster’s New World Dictionary of Computing (3d ed. 1988) (defining “switch” as “a device used to open, close, or divert an electric circuit”))).

We also find it relevant that at some point during the district court litigations, Patent Owner itself agreed to Petitioner’s proposed construction. Patent Owner argues that the Orlando Court’s later construction of the term “trumps any agreement the parties made in litigation.” PO Sur-reply 5. Patent Owner’s argument, however, misses the point. Although the court’s construction is binding on the parties before the court, it does not alter the fact that Patent Owner, at one point, independently understood Petitioner’s proposed construction to be the proper construction of the term.

Based on our review of the complete record before us, including the intrinsic and extrinsic evidence, we determine that one of ordinary skill in

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the art would understand “switch” to mean “an electronic device for opening and closing a circuit.” With that construction of the term “switch,” we do not find it necessary to further construe the term “third switch.”

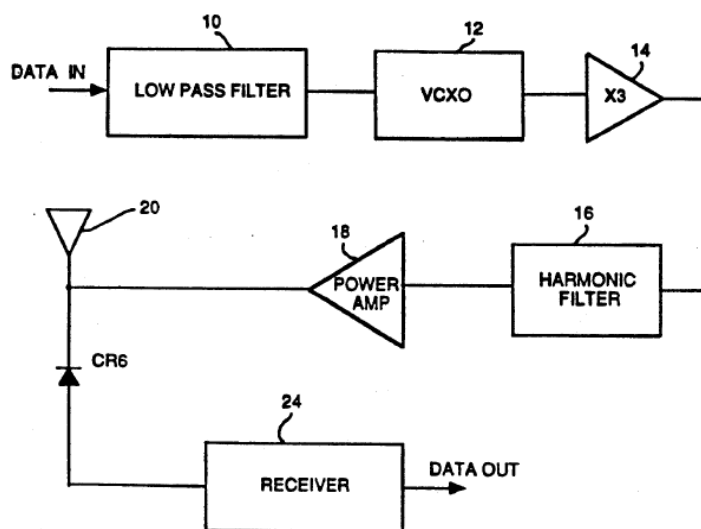
*D. Overview of the Asserted Prior Art*

*1. Downey (Ex. 1003)*

Downey is titled “Transceiver with Rapid Mode Switching Capability” and describes a need for “a lightweight, compact and inexpensive [radio frequency (“RF”)] transceiver that can switch rapidly from the receive mode to the transmit mode.” Ex. 1003, code (54), 1:51–54. To that end, Downey’s transceiver “achieves a fast switching time between transmit and receive mode by leaving the transmit oscillator on all the time,” which “eliminates the start up time of up to about five milliseconds.” *Id.* at 1:61–65. The transmit oscillator operates “at one third the transmit frequency followed by a frequency tripler/filter/amplifier chain that can be quickly switched on and off.” *Id.* at 1:68–2:6 (explaining that “only the third harmonic of the oscillator falls into the sensitive receive frequency band”).

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Figure 1 of Downey is reproduced below.



**FIG. 1**

Figure 1 shows a block diagram of an embodiment of Downey's transceiver. *Id.* at 2:25–26, 2:53–54. Digital data “is asserted at low pass filter 10 where high frequency components of the data bit stream are removed prior to modulation of an RF signal.” *Id.* at 2:54–60. “The output of low pass filter 10 is asserted at voltage controlled crystal oscillator (VCXO) 12, which frequency modulates the oscillator's RF signal.” *Id.* at 2:60–62. “VCXO 12 operates at a fundamental frequency that is one third of the transceiver's communication frequency.” *Id.* at 2:64–66. “The modulated RF output of VCXO 12 is asserted at frequency tripler 14 where harmonics, particularly the third harmonic, of the crystal oscillator signal are generated.” *Id.* at 2:67–3:2. “The output of frequency tripler 14 is asserted at harmonic filter 16 which selectively passes the third harmonic (at the communication frequency of the transceiver).” *Id.* at 3:2–5. “The RF signal from harmonic

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filter 16 is asserted at power amplifier 18 where the signal power is boosted to a level sufficient for transmission.” *Id.* at 3:5–7. “The signal from power amplifier 18 is coupled to antenna 20 which radiates the transmit signal.” *Id.* at 3:8–10.

Figure 2c of Downey is reproduced below.

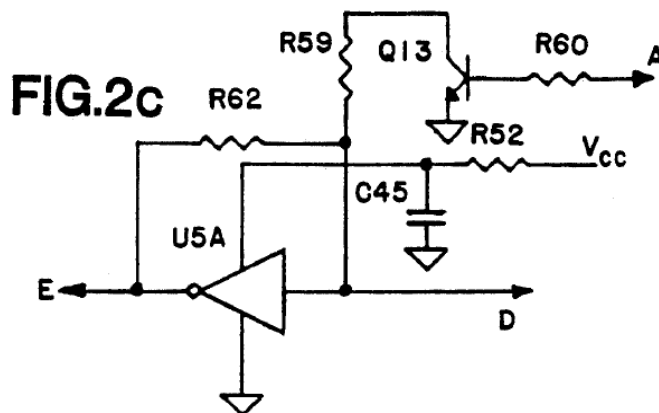


Figure 2c shows a frequency tripler circuit for Downey’s transceiver. *Id.* at 2:33–34, 4:8–9. “The output of VCXO 12 (signal D) is asserted at the input of inverter U5A.” *Id.* at 4:9–10. Inverter U5A outputs “harmonics of the input signal, particularly the third harmonic which will drive the RF power amplifier.” *Id.* at 4:10–13. “The input of inverter U5A is grounded through transistor Q13 in the receive mode . . . thereby preventing the generation of any harmonics of VCXO 12 during the receive mode.” *Id.* at 4:15–19.

## 2. Sedra (Ex. 1004)

Sedra is titled “Microelectronic Circuits,” and is a book “intended as a text for the core courses in electronic circuits taught to majors in electrical and computer engineering.” Ex. 1004, v (Preface). The objective of the book is “to develop in the reader the ability to analyze and design electronic circuits, both analog and digital, discrete and integrated.” *Id.* Sedra discusses

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“some basic concepts that underlie the design and specification of logic gate circuits.” *Id.* at 908.

A portion of Figure 13.2 of Sedra is reproduced below.

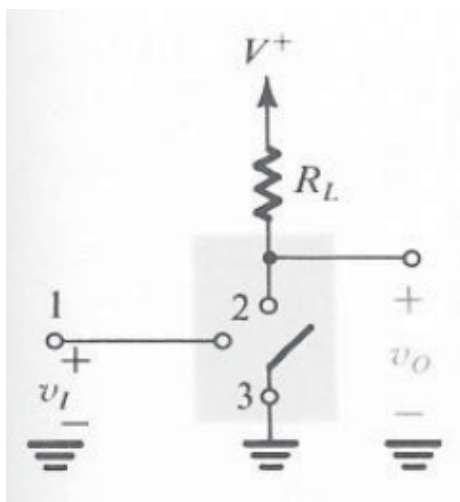


Figure 13.2 is “[a] conceptual representation of the logic inverter.” *Id.* at 909. Sedra explains that “[t]he logic inverter is basically a voltage-controlled switch such as that represented schematically in Fig[ure] 13.2.” *Id.* at 908. Sedra further explains that “[p]ractical implementations of a logic inverter utilize a transistor (a [metal–oxide–semiconductor field-effect transistor (MOSFET)] or a [bipolar junction transistor (BJT)]) as the switching element and a resistor or another transistor for the load resistor  $R_L$ .” *Id.* at 909.

### 3. *Hahnel* (Ex. 1005)

*Hahnel* is titled “Frequency Multiplier Circuit,” and relates to “a frequency multiplier where a high degree of multiplication is desired at a prescribed frequency.” Ex. 1005, 1:4, 1:18–21. *Hahnel* describes a circuit with “a source of fundamental frequency voltage and a pulse shaper responsive to the fundamental frequency voltage and adapted to produce

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gating pulses having a repetition frequency equal to the fundamental frequency.” *Id.* at 1:59–63.

Figure 1 of Hahnel is reproduced below.

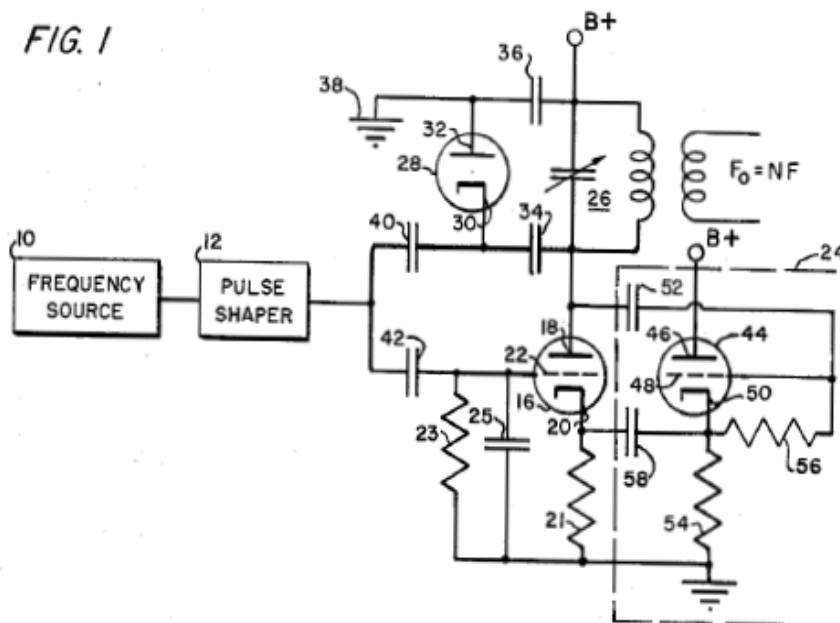


Figure 1 illustrates a schematic representation of Hahnel’s circuit. *Id.* at 2:19–20. Hahnel’s circuit includes “a source [10] of frequency voltage  $F$  which may comprise any suitable oscillator designed to produce a stable frequency output.” *Id.* at 2:24–26. “The output of frequency source 10 is applied to pulse shaper 12 for producing a substantially square-shaped voltage wave.” *Id.* at 2:26–28. “The square-wave output of pulse shaper 12 controls the duration of the period of oscillation of a harmonic frequency generator,” comprising other components of the circuit shown in Figure 1. *Id.* at 2:43–48.

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*E. Obviousness of Claims 1 and 12 over Downey and Sedra*

Petitioner contends that claims 1 and 12 are unpatentable as obvious over the combination of Downey and Sedra. Pet. 41–67, 84–85. To support its contentions, Petitioner provides, among other things, explanations as to how the prior art teaches each claim limitation. *Id.* Petitioner also relies upon Dr. van der Weide’s testimony (Exs. 1002, 1035) to support its positions. *Id.*

Patent Owner argues that Petitioner’s proposed obviousness combination fails to teach each of the three “switch” limitations recited in claims 1 and 12. PO Resp. 46–49. On the complete record, we are persuaded by Petitioner’s explanations and evidence in support of the obviousness ground for claims 1 and 12 over Downey and Sedra. We address below the evidence, analysis, and arguments presented by the parties.

*1. Independent Claim 1*

*a) Element [1Preamble]: “A frequency conversion module, comprising”*

Petitioner contends that, to the extent the preamble is limiting, Downey teaches the preamble because Downey discloses a frequency conversion module. Pet. 41. In particular, Petitioner contends that “Downey discloses a transceiver that up-converts the frequency of the modulating oscillating control signal from the VCXO by using a ‘frequency tripler’ that triples the frequency of the signal.” *Id.* (citing Ex. 1003, 1:67–2:10, 2:60–3:5, 3:53–57, 4:9–13, 4:20–25, Figs. 1, 2a–2e; Ex. 1002 ¶¶ 77–78). Patent Owner does not present arguments as to the preamble. *See generally* PO Resp. Based on the entirety of the record and for the reasons explained by Petitioner, we determine that, to the extent the preamble is limiting,

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Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches the preamble.

*b) Element [1A]: “a first switch configured to up-convert a signal based on a control signal and a bias signal”*

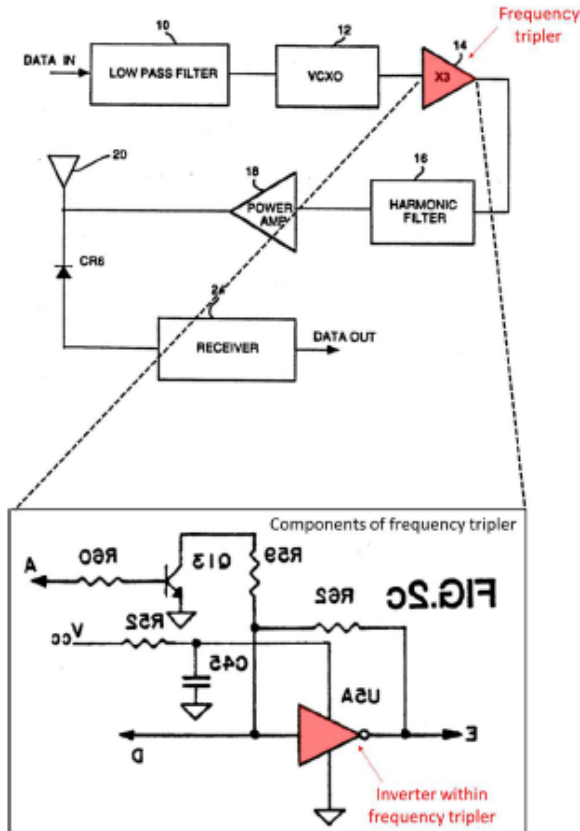
Petitioner contends that Downey in view of Sedra teaches this limitation. Pet. 41.

*(1) “a first switch configured to up-convert a signal”*

Petitioner contends that Downey’s frequency tripler 14 includes an inverter U5A that up-converts a modulated signal from voltage controlled crystal oscillator (VCXO) 12. Pet. 41–45 (citing Ex. 1002 ¶¶ 79–86). Petitioner contends that in Downey’s system, an information signal is routed through a low pass filter 10 and output to VCXO 12. *Id.* at 42 (citing Ex. 1003, 2:54–61, Fig. 1). Petitioner further contends that the VCXO operates at a frequency that is one-third of the frequency of the signal ultimately transmitted. *Id.* at 42–43 (citing Ex. 1003, 2:64–66, 3:54–56; Ex. 1002 ¶ 81). The modulated oscillating signal supplied to frequency tripler 14 from the VCXO thus has a frequency of 16.628 MHz. *Id.* at 43–44 (citing Ex. 1002 ¶ 83). Petitioner contends frequency tripler 14 “creates a harmonically rich signal that includes the third harmonic (with a frequency of 49.885 MHz (3 x 16.628 MHz)) of the modulated oscillating signal.” *Id.* at 44 (citing Ex. 1003, 2:66–3:2; Ex. 1002 ¶ 84). Petitioner contends this tripling of the modulated oscillating signal amounts to an up-conversion of the modulated oscillating signal to the desired output communications frequency. *Id.* at 44–45 (citing Ex. 1003, 2:64–66, 3:54–56; Ex. 1002 ¶ 85).

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Petitioner further contends Downey in view of Sedra teaches up-converting a signal with a switch. *Id.* at 45. Petitioner's annotated version of Figures 1 and 2c of Downey are reproduced below.

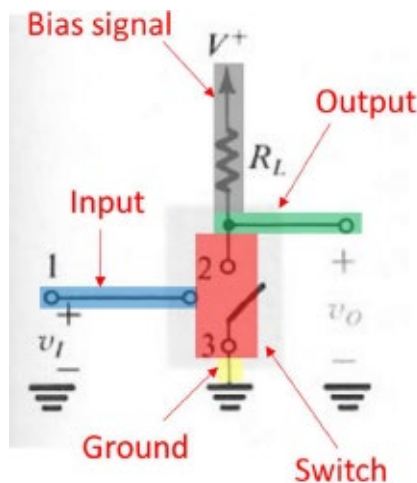


*Id.* Figure 2c is a schematic diagram of Downey’s frequency tripler circuit (Ex. 1003, 2:32–34), which Petitioner has rotated and combined with Figure 1 of Downey, providing annotations (in red) to show that Downey’s frequency tripler 14 includes inverter U5A. Pet. 45–46 (citing Ex. 1003, 4:8–13). Petitioner contends that the inverter “is the component that up-converts the modulated oscillating signal to the third harmonic.” *Id.* Petitioner further contends that “[i]t was well-known in the art that an

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inverter is a switch,” and that “Sedra expressly discloses that an inverter is ‘basically a . . . switch.’” *Id.* at 46 (citing Ex. 1004, 908–09; Ex. 1002 ¶ 87).

Petitioner’s annotated version of Figure 13.2 of Sedra is reproduced below.



*Id.* at 48. Figure 13.2 of Sedra (above) includes Petitioner’s annotations showing Sedra’s inverter switch (red) with one terminal connected to a bias signal (grey) and another to ground (yellow). *Id.* at 48–49 (citing Ex. 1004, 908–10; Ex. 1002 ¶ 91). Petitioner contends that “Sedra explains that an inverter includes a switch, such as a transistor, that opens and closes to either allow signals to pass or prevent them from doing so—just like the switch of the ’108 patent.” *Id.* at 49–50 (citing Ex. 1001, 33:33–55, 55:12–20; Ex. 1004, 908–10; Ex. 1002 ¶ 92).

## (2) Rationale to Combine Downey and Sedra

Petitioner contends that “a POSITA would have been motivated to combine Sedra with Downey. Specifically, a POSITA would have been motivated to use Sedra to design the inverter of Downey and would have had a reasonable expectation of success of doing so.” Pet. 50 (citing Ex. 1002 ¶ 93). Petitioner contends that “both Sedra and Downey describe the use of

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inverters in signal processing” (*id.* (citing Ex. 1003, 4:10–13; Ex. 1004, 1, 911, 930; Ex. 1002 ¶ 94)), and “Sedra provides the additional details of the structure of Downey’s inverter,” i.e., it “shows the components and structure to use in such an inverter” (*id.* (citing Ex. 1004, 908–09; Ex. 1002 ¶ 95)), and also “discloses benefits of using a switch within the inverter in a system like Downey” (*id.* at 51). In particular, with respect to Sedra’s alleged benefits, Petitioner contends that one of Downey’s goals “is to provide a compact transceiver” and Sedra “accomplishes this goal because switching elements—such as [metal–oxide–semiconductor (MOS)] transistors—are small and energy efficient.” *Id.* (citing Ex. 1003, 1:51–52; Ex. 1004, 906). Petitioner further contends that using Sedra’s switch to design Downey’s inverter would thus yield predictable benefits and result in an improved inverter that can be used to process signals for transmission. *Id.* at 51–52 (citing Ex. 1002 ¶ 96).

Petitioner argues that a person of ordinary skill in the art would have had a reasonable expectation of success combining Downey with Sedra because the “combination is simply the application of known techniques to a known device,” and given Sedra’s disclosure, “a POSITA would have had a roadmap of how to construct the inverter of Downey—specifically, by using the switch disclosed in Sedra within the inverter of Downey.” *Id.* at 52 (citing Ex. 1002 ¶ 97).

### (3) Patent Owner’s Response

Patent Owner argues that “[i]nverter U5A in the frequency tripler circuit of Downey is not configured as a switch, nor can it be without rendering the circuit unsuitable for its intended purpose.” PO Resp. 48. Patent Owner argues that “inverter U5A is not toggled between an open and

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closed state, but instead is configured to operate as a ‘non-linear amplifier.’”  
*Id.* at 48–49 (citing Ex. 1003, 4:10–13; Ex. 2022 ¶ 197). According to Patent Owner, a person of ordinary skill in the art would have understood that “a [complementary metal-oxide semiconductor (‘CMOS’)] inverter with appropriate feedback ensures that the transistor operates [in] its active region (i.e., it is always ON/conducting current).”<sup>14</sup> *Id.* at 49 (citing Ex. 1003, Fig. 2c; Ex. 2021; Ex. 2022 ¶ 198). Patent Owner contends such a configuration “is essential to the operation of Downey’s ‘frequency tripler’ circuit that uses the nonlinear function to ‘develop harmonics of the input signal, particularly the third harmonic.’” *Id.* (citing Ex. 1003, 4:10–13). Patent Owner argues that there is no teaching, suggestion, or motivation in Downey to use an inverter as a switch for up-conversion nor would it have been obvious or inherent to a person of ordinary skill in the art to modify the inverter in Downey (which operates as a non-linear amplifier) to operate as a completely different device—a switch. *Id.* at 50 (citing Ex. 2022 ¶ 199).

As to Petitioner’s proposed combination of Downey and Sedra, Patent Owner contends that “[i]mplementing the transistor of Sedra with the inverter of Downey would not change the operation of Downey’s frequency tripler circuit,” and “one would have to ignore all of the disclosure in Downey, and abandon all of the teachings and suggestions of Downey,” using hindsight to modify Downey to arrive at the claimed invention. PO Resp. 49–50 (citing Ex. 2022 ¶ 200).

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<sup>14</sup> Downey’s disclosed circuit component for U5A inverter is “74HC04” (*see* Ex. 1001, 5:21), and Patent Owner relies on an Application Note from Fairchild Semiconductors titled “CMOS Linear Applications,” which discusses a MM74C04 inverter. *See* Ex. 2021; Ex. 2022 ¶ 198.

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(4) *Petitioner's Reply*

Petitioner responds that although Downey discloses an inverter for performing up-conversion, the Petition also relies on the combination of Downey and Sedra, “which specifically describes an inverter like Downey’s . . . and states that an ‘inverter is basically a voltage-controlled switch.’” Pet. Reply 8–9 (citing Ex. 1004, 908; Ex. 1030 ¶¶ 5–6). Petitioner asserts that Patent Owner’s arguments ignore Sedra’s disclosure. *Id.* at 9. Petitioner contends that “Sedra’s inverter has the same configuration as the ‘first switch’ disclosed in the ’108 patent—a fact that PO does not dispute.” *Id.* Petitioner asserts that “Downey in combination with Sedra thus plainly disclose the claimed ‘first switch.’” *Id.* at 10 (citing Ex. 1001, Fig. 28A; Ex. 1004, 908).

Petitioner further contends that Patent Owner is also wrong that Downey alone does not disclose the required switch because Patent Owner’s argument that a non-linear amplifier is different from a switch is based on “two demonstrably incorrect propositions: (1) an inverter cannot function as both a ‘switch’ and ‘amplifier’ at the same time; and (2) a ‘non-linear’ amplifier cannot be a switch.” Pet. Reply 10–11 (citing Ex. 1030 ¶ 9). Petitioner contends that basic engineering textbooks, including one authored by Dr. Steer, show that amplifiers and switches are not mutually exclusive components. Pet. Reply 11–12 (citing Ex. 1031, 116–22; Ex. 1035, 174; Ex. 1030 ¶¶ 11–12). Petitioner argues that “it is precisely the operation of Downey’s inverter as a non-linear amplifier—and the resulting square-wave waveform—that allows Downey to upconvert a signal as described in Downey (and in the ’108 patent).” *Id.* at 14–15 (citing Ex. 1003, 2:67–3:5, 4:10–13; Ex. 1030 ¶¶ 18–23); *see also id.* at 15–20 (explaining the

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difference between linear and non-linear amplifiers) (citing Ex. 1004, 13, Fig. 1.11; Ex. 1030 ¶¶ 21–25).

*(5) Patent Owner's Sur-reply*

In its Sur-reply, Patent Owner argues that Petitioner “ignores that there are *other* types of amplifiers that are a compromise between these two types of amplifiers,” such as those “that operate in an active region (linear/non-linear modes) without causing the amplifier to saturate.” PO Sur-reply 11 (citing Ex. 1031, 136; Ex. 1038, 146). Patent Owner further argues that “amplifiers, such as inverter U5A (part no. 74HC04) as configured in Downey, are never ‘purely linear’ and will always ‘exhibit harmonic content or other distortions.’” *Id.* (citing Ex. 2023, 107:18–110:22; Ex. 1032, 14–17). Patent Owner points to the voltage transfer characteristic of the MM74C045 inverter to argue that Downey’s inverter operates in both linear and non-linear modes. *Id.* at 12–13 (citing Ex. 2021, Fig. 1; Ex. 2023, 131:16–132:10, 132:11–24). Patent Owner asserts, without support, that “[b]ecause the amplifier operates in both linear and non-linear modes, it is sometimes referred to as a non-linear amplifier.” *Id.* at 13. Patent Owner further argues that a “pure non-linear amplifier can use transistors that operate in two discrete regions — saturation region and cut-off/pinch-off region.” *Id.* (citing Ex. 2022 ¶¶ 133–143). Patent Owner asserts that “a continuously-ON non-linear amplifier can use transistors that operate in the saturation region and triode/linear region.” *Id.* (citing Ex. 2022 ¶¶ 137–138). According to Patent Owner, “[i]nverter U5A in Downey is a continuously-ON non-linear amplifier,” and “does not operate as a pure non-linear amplifier.” *Id.* at 14.

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As to Petitioner’s proposed combination of Downey and Sedra, Patent Owner argues that “implementing Downey’s inverter U5A with the transistor of Sedra would not change this operation.” PO Sur-reply 8 (citing PO Resp. 49). Patent Owner argues that “[u]nlike a switch, inverter U5A of Downey (implemented with the transistor of Sedra) is not opening a circuit.” *Id.* (citing PO Resp 48–49; Ex. 2022 ¶¶ 195–198).

(6) *Our Analysis*

Having fully considered the parties’ arguments and evidence, we conclude that Petitioner has shown by a preponderance of the evidence that the combination of Downey and Sedra discloses this limitation.

Patent Owner’s arguments focus on Petitioner’s contention that Downey alone discloses this limitation. As discussed above, Patent Owner argues at length about why inverter U5A in Downey’s frequency tripler circuit is not configured as a switch and does not operate as a switch. Patent Owner’s arguments are based on the specific circuit components shown in Downey’s frequency tripler circuit and characteristics of the MM74C04 inverter. Patent Owner does not address Petitioner’s contention that the combination of Downey and Sedra also teaches this limitation, except to argue that Sedra’s inverter when combined with Downey “would not change the operation of Downey’s frequency tripler circuit,” and that a person of ordinary skill in the art “would have to ignore all of the disclosure in Downey, and abandon all of the teachings and suggestions of Downey” to combine the two references. PO Resp. 49–50. Patent Owner therefore does not meaningfully address Petitioner’s proposed combination. *See In re Mouttet*, 686 F.3d 1322, 1333 (Fed. Cir. 2012) (“the test for obviousness is what the combined teachings of the references would have suggested to

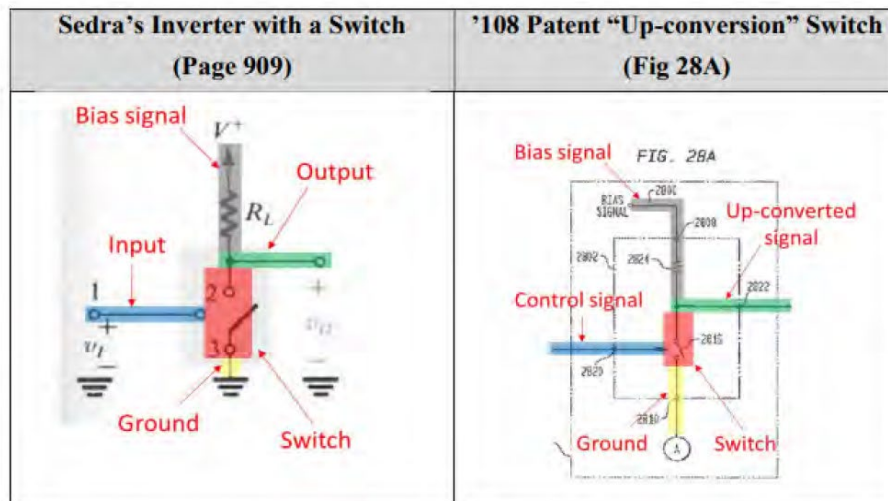
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those having ordinary skill in the art”) (citing *In re Keller*, 642 F.2d 413, 425 (CCPA 1981)).

The claims require “a first *switch* configured to up-convert.” Sedra specifically discloses a *switch* used to implement an inverter, and also states that an “inverter is basically a voltage-controlled switch”—disclosure that Patent Owner does not dispute. See Ex. 1004, 908–09, Fig. 13.2. Patent Owner also does not dispute that Downey’s frequency tripler circuit includes an inverter that upconverts the input signal. Ex. 1003, 4:8–13. Patent Owner’s arguments are directed to the inverter U5A that operates as a non-linear amplifier, as disclosed in Downey. PO Resp. 46–50. Patent Owner specifically argues “[i]nverter U5A in the frequency tripler circuit of Downey is *not configured as a switch*, nor can it be without rendering the circuit unsuitable for its intended purpose.” PO Resp. 48. But Sedra’s inverter *is a switch*. Patent Owner does not explain why a switch-based inverter would not work in Downey to accomplish the up-conversion.

Petitioner offers persuasive evidence that Petitioner’s combined circuit not only meets the claim limitation, but also looks and functions similar to the one disclosed in the ’108 patent Specification. Petitioner’s comparison of Sedra’s inverter with the ’108 patent’s up-conversion switch is reproduced below.

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Pet. Reply 10 (citing Ex. 1001, Fig. 28A; Ex. 1004, 908). Petitioner's comparison above shows Sedra's inverter alongside Figure 28A of the '108 patent, with annotations showing the various input and output signals to each of the switches. As shown in Petitioner's comparison of the two figures, Sedra's inverter has the same configuration as the switch corresponding to the claimed "first switch" in the '108 patent. Dr. van der Weide testifies that "[b]oth switch configurations include a transistor symbolized as an ideal switch (red), which opens and closes a circuit between the bias signal (gray) and ground (yellow)." Ex. 1030 ¶ 8 (citing Ex. 1002 ¶¶ 91–92). Dr. van der Weide further testifies that Sedra describes that "an inverter includes a switch, such as a MOSFET or BJT transistor, that closes to allow a signal to pass through it and opens to prevent signals from passing through it." Ex. 1002 ¶ 92 (citing Ex. 1004, 908–10). Dr. van der Weide testifies that "when the switch opens and closes, the output signal (green) fluctuates between 1V and 0V," and therefore, the output signal is a square wave. *Id.* Dr. van der Weide testifies that this is the same function as the switch of the '108 patent. *Id.* (citing Ex. 1001, 32:43–45, 33:33–55,

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42:65–43:16, 55:12–20). We find Dr. van der Weide’s testimony persuasive because it is based on the disclosure of the ’108 patent and Sedra.

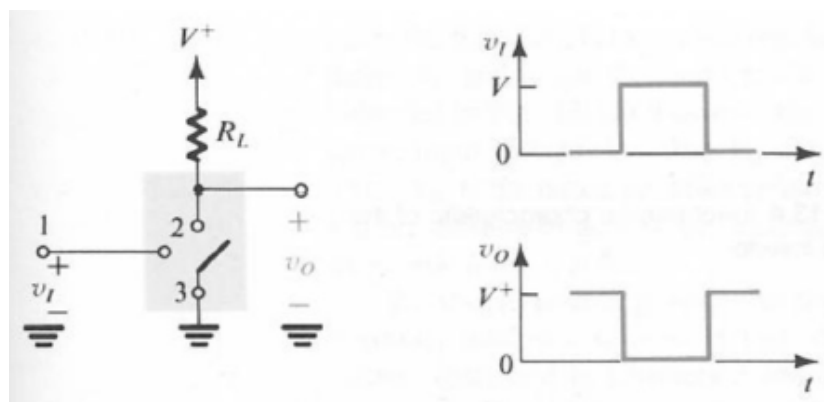
Petitioner also provides adequate reasons with rational underpinning as to why a person of ordinary skill in the art would have been motivated to combine the teachings of Downey and Sedra, including because Sedra accomplishes Downey’s goal of providing a compact transceiver by using small and energy efficient MOS transistors. Pet. 51–52 (citing Ex. 1003, 1:51–52; Ex. 1004, 906; Ex. 1002 ¶ 96). Sedra provides a roadmap of how to construct an inverter to be used in the circuit of Downey, and a person of ordinary skill in the art would thus have had a reasonable expectation of success in Petitioner’s proposed combination. *Id.* at 52 (citing Ex. 1002 ¶ 97). Dr. van der Weide testifies that an ordinarily skilled artisan would have understood from Sedra that a switch connected to a voltage supply through a resistor is an inverter and that “this circuit realizes the logic inversion operation,” allowing it to be used as an inverter in Downey’s circuit. *See* Ex. 1002 ¶ 97 (citing Ex. 1004, 908–09, Fig. 13.2). We credit Dr. van der Weide’s testimony because it is based on Sedra’s disclosure.

Patent Owner and Dr. Steer fail to address Petitioner’s arguments or Dr. van der Weide’s testimony on motivation to combine. *See* PO Resp. 49–50 (citing Ex. 2022 ¶ 200); PO Sur-reply 8–9 (citing PO Resp. 49). Instead, Patent Owner’s arguments focus on Downey’s disclosed inverter functioning as a non-linear amplifier and the related circuitry in Downey’s frequency tripler circuit. For example, Patent Owner argues that the inverter in Downey is a special type of non-linear amplifier that is always ON and is

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therefore not a switch.<sup>15</sup> See PO Resp. 48–50; PO Sur-reply 11–14. Patent Owner points to the existence of resistor R62 in Downey’s circuit to argue that a person of ordinary skill in the art would have considered inverter U5A “operates [in] its active region (i.e., it is always ON/conducting current).” PO Resp. 49 (citing Ex. 2022 ¶ 198; Ex. 2021).

Patent Owner does not however address why a person of ordinary skill in the art looking to use Sedra’s inverter to design Downey’s inverter would alter Sedra’s *switch* circuit to something else, or why the combined circuit would also have the same non-switch characteristics that Patent Owner contends render Downey’s inverter deficient in teaching this limitation. See Ex. 1004, 908–09. Figure 13.2 of Sedra is reproduced below.



*Id.* at 909. Figure 13.2 is “[a] conceptual representation of the logic inverter.” *Id.* Sedra discloses its inverter circuit operates as a switch that

<sup>15</sup> Petitioner contends that a person of ordinary skill in the art would have understood that a non-linear amplifier is one that toggles between open and closed states. Pet. Reply 12–13 (citing Ex. 1033, 8 (“Non-linear amplifiers operate such that the transistor is saturated (‘fully-ON’) o[r] cut-off (‘fully-OFF’), no intermediate state”). Patent Owner contends that Downey’s inverter is a special non-linear amplifier that is continuously-ON. PO Sur-reply 13.

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fluctuates between open and close positions depending on the input signal, and produces a square wave output signal that is the inverted form of the input signal. *Id.* at 908–09. Sedra explains that the inverter transfer characteristic of its inverter indicates that it is “a grossly nonlinear device,” which is consistent with the mode that Downey states its inverter should operate in. *Id.* at 911; Ex. 1003, 4:10–13. Downey states that it is the non-linear operation that allows Downey’s circuit to up-convert a signal and act as a frequency tripler. Ex. 1003, 4:10–13. It is therefore unclear why a person of ordinary skill in the art considering combining Sedra’s inverter with Downey’s circuit would alter the configuration of Sedra’s inverter from a mode that Downey states enables up-conversion to a different mode that Patent Owner alleges does not meet the claim limitation.<sup>16</sup> *See* Ex. 1030 ¶¶ 13–16. Rather, we find it more likely, as argued by Petitioner and supported by Dr. van der Weide’s testimony, that an ordinarily skilled artisan would have understood from Sedra that a switch connected to a voltage supply through a resistor realizes the logic inversion operation, allowing it to be used as an inverter in Downey’s circuit just as it is disclosed in Sedra. Pet. 52 (citing Ex. 1002 ¶ 97).

Nor do we agree with Patent Owner’s argument that a person of ordinary skill in the art would have understood that the use of resistor R62 suggests that the U5A inverter is in continuously on mode. Petitioner cites an example of at least one other reference that discloses the use of a similar resistor configuration with an inverter where the output waveform represents

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<sup>16</sup> Notably, Patent Owner does not argue that the combined circuit would not accomplish the up-conversion. *See* PO Resp. 49 (arguing that “implementing the transistor of Sedra with the inverter of Downey would not change the operation of Downey’s frequency tripler circuit”).

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the ON and OFF values indicating that the inverter turns on and off. *See* Ex. 1030 ¶ 27 (citing Ex. 1034, Fig. 4a.); Pet. Reply 18–20 n.6. To the extent Patent Owner argues that the presence of resistor R62 would have resulted in a continuously on state in the combined circuit with Sedra’s inverter, “the test for obviousness is not whether the features of a secondary reference may be bodily incorporated into the structure of the primary reference.” *In re Keller*, 642 F.2d at 425. “Rather, the test is what the combined teachings of the references would have suggested to those of ordinary skill in the art.” *Id.* The presence of a feedback resistor in Downey’s circuit therefore does not undermine the combined teachings of Downey’s circuit with Sedra’s inverter.

Lastly, we reject Patent Owner’s argument that a sinusoidal input to Downey’s U5A inverter suggests that the inverter always stays on. *See* PO Sur-reply 14 n.6 (“unlike a switch, inverter U5A of Downey receives a sinusoidal input signal”); Tr. 54:7–20. We see no support in the record to find that a sinusoidal input signal prevents a switch from operating between on and off states; as Petitioner points out, Patent Owner’s position is at odds with the very disclosure of the ’108 patent. *See, e.g.*, Ex. 1001, 33:1–11 (explaining that the modulating input signal can be a sinusoidal wave, causing the switch to open and close); Tr. 64:7–65:3.

Fundamentally, Patent Owner does not explain how its arguments relating to Downey’s circuit would be applicable to Petitioner’s proposed combined circuit which in fact does utilize a “switch.” Patent Owner argues that “one would have to ignore all of the disclosure in Downey, and abandon all of the teachings and suggestions of Downey” to arrive at the combination

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(PO Resp. 50), but we find no teachings in Downey that dissuade Petitioner’s proposed combination.

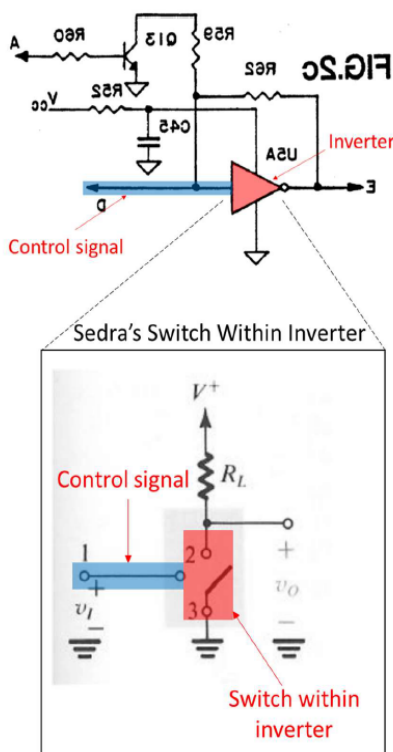
We are therefore persuaded that a person of ordinary skill in the art would have been motivated to combine Downey and Sedra in the manner proposed by Petitioner and would have had a reasonable expectation of success for the combination. We are therefore persuaded that the combination of Downey and Sedra teaches this limitation.

(7) *“based on a control signal and a bias signal”*

Petitioner contends that Downey teaches using a control signal and a bias signal to up-convert a signal with a switch. Pet. 52 (citing Ex. 1002 ¶ 98). In particular, Petitioner contends that “the modulated oscillating signal from [Downey’s] VCXO 12 controls the switch within the inverter of Downey and Sedra—just like the control signal from the ’108 patent’s VCO controls the switch.” *Id.* at 54 (citing Ex. 1003, 3:53–54, 4:8–10, 4:16–19, Fig. 2c; Ex. 1004, 908).

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Petitioner's annotated versions of Figure 2c of Downey and Figure 13.2 of Sedra are reproduced below.



*Id.* at 55. Figure 2c is a schematic diagram of Downey's frequency tripler circuit (Ex. 1002, 2:12–14), which Petitioner has rotated and combined with Figure 13.2 of Sedra to show a control signal (blue) applied to Sedra's switch (red) shown as being within Downey's frequency tripler's inverter. *Id.* (citing Ex. 1002 ¶ 101).

Petitioner contends that Downey's signal  $V_{CC}$  teaches a bias signal. *Id.* at 56 (citing Ex. 1003, 3:30–31). Petitioner contends that "the control and bias signals of Downey in view of Sedra operate the same way as the signals of the '108 patent," that is, "[t]he control signal causes Downey's inverter (implemented with Sedra's switch) to open and close," and "[w]hen

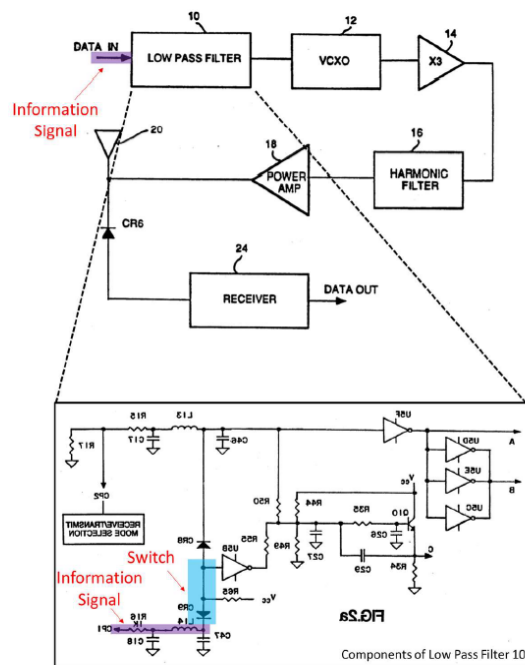
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the switch is open, the switch outputs the bias signal voltage  $V_{CC}$ .” *Id.* at 58–59 (citing Ex. 1001, 55:12–20; Ex. 1003, 4:8–19; Ex. 1002 ¶ 104).

Patent Owner does not present arguments as to this limitation. *See generally* PO Resp. Based on the entirety of the record and for the reasons explained by Petitioner, we determine that Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches this claim limitation.

c) *Element [1B]: “wherein said signal are routed to said frequency conversion module via a second switch, and”*

Petitioner contends that Downey teaches this limitation. Pet. 59–61. Petitioner’s annotated version of Figures 1 and 2a of Downey are reproduced below.



*Id.* at 60. Figure 2a is a schematic diagram of Downey’s low pass filter circuit (Ex. 1003, 2:27–27), which Petitioner has rotated and combined with Figure 1 of Downey to argue that “Downey discloses diode CR9 (second

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switch (light blue)) that routes the input data to be up-converted to the VCXO via a low pass filter.” *Id.* at 59–60 (citing Ex. 1003, 3:19–52, Figs. 1, 2a; Ex. 1002 ¶ 105). Petitioner further contends “[t]he ’108 patent specifically refers to diodes as switches.” *Id.* at 61 (citing Ex. 1001, 33:60–61; Ex. 1012, Figs. 28C–28D, 56:26–33; Ex. 1002 ¶ 106).

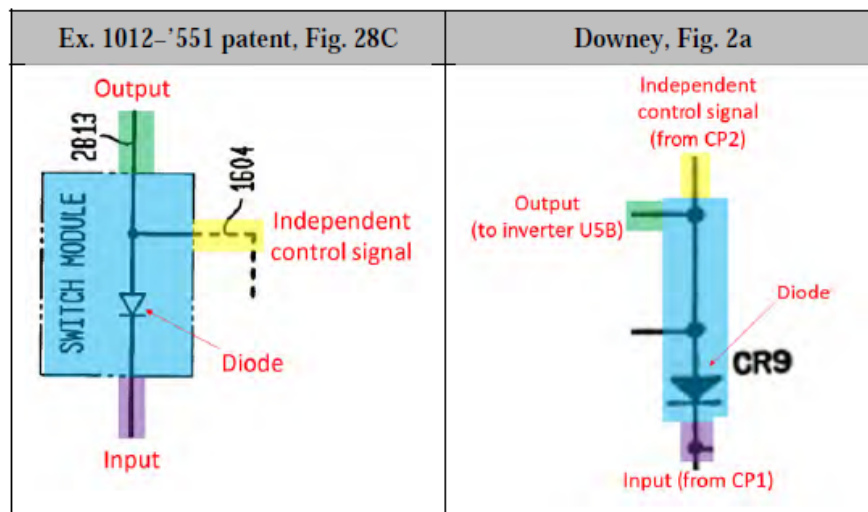
Patent Owner responds that Downey’s diode CR9 is not a switch because it is not “an electronic device for opening and closing a circuit *as dictated by an independent control input.*” PO Resp. 51 (citing Ex. 2022 ¶ 202). Patent Owner asserts that the ’108 patent does not refer to a diode as switch, but instead refers to a “diode ring” as a switch, and person of ordinary skill in the art would have understood the two to be different. *Id.* (citing Ex. 2022 ¶ 203).

In its Reply, Petitioner argues that Patent Owner’s argument that CR9 is not a switch is based on Patent Owner’s improper construction of “switch,” requiring an “independent control input.” Pet. Reply 21. Petitioner argues that Downey discloses, with reference to Figure 2a (reproduced above), that when the receive/transmit signal CP2 is high, the transceiver is in transmit mode, and diode CR9 allows the information signal CP1 to pass through to inverter U5B, and when CP2 is low, diode CR9 prevents information signal CP1 from passing through. *Id.* at 22–21 (citing Ex. 1003, 3:27–30, Fig. 2a; Ex. 1030 ¶¶ 30–36).

Moreover, Petitioner asserts that, in the parallel litigation, Patent Owner has argued that various diodes with similar configuration as Downey’s, disclosed in U.S. Patent No. 6,061,551 (“the ’551 patent”), which is incorporated by reference in the ’108 patent, meet the “switch” limitation. Pet. Reply 24–27 (citing Ex. 1040, 12–13; Ex. 1012, 56:60–62,

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Figs. 28A–C; Ex. 1030 ¶¶ 39–40). Petitioner’s comparison of Figure 28C from the ’551 patent and Figure 2a from Downey is reproduced below.



Pet. Reply 26. Petitioner’s annotations show the various inputs and outputs to the diode shown in each of the two figures in support of Petitioner’s argument that Downey’s diode CR9 has the same structure in all relevant respects as the “diode switch” in Figure 28C of the ’551 patent. *Id.* at 25–26. Petitioner contends that Patent Owner’s argument that Downey’s diode CR9 is not a “switch,” thus directly contradicts both the ’108 patent’s disclosure and Patent Owner’s representations in district court. *Id.* at 27.

In its Sur-reply, Patent Owner argues that Downey’s diode CR9 does not receive an independent control input because diode CR8 prevents signal CP2 from reaching CR9. PO Sur-reply 19–22. According to Patent Owner, diode CR8 in Downey’s circuit makes the configuration different than the one shown in Figure 28C of the ’551 patent. *Id.* at 22–23. Patent Owner also seeks to distinguish arguments that it made to the district court by arguing that Patent Owner never stated to the court that a diode by itself is a “switch,” but instead represented to the court that the module containing the

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diode is the switch. *Id.* at 23–25. Patent Owner argues, for the first time, that diode CR9 is not a switch because “a diode (similar to a one-way valve) only allows current to flow in one direction,” and is therefore not closing a circuit. *Id.* at 18; Tr. 60:6–13.

To begin, we agree with Petitioner that the arguments asserted in Patent Owner’s Response, and Dr. Steer’s testimony in support thereof, are entirely dependent upon Patent Owner’s proposed construction of “switch,” which we do not adopt.

We consider Patent Owner’s new argument raised in Patent Owner’s Sur-reply (PO Sur-reply 18) to be untimely. *See NuVasive*, 842 F.3d at 1380–81 (holding that the patent owner waived arguments that were not raised in its response after institution); Paper 13, 8 (“Patent Owner is cautioned that any arguments not raised in the response may be deemed waived.”). Even if not waived, we find no evidentiary support for Patent Owner’s requirement that a switch has to permit *bidirectional* current flow in order to be in a closed state. PO Sur-reply 18 (citing PO Resp. 21). As a threshold matter, Patent Owner’s proposed construction for the term “switch” does not require such bidirectional current flow. Further, Patent Owner fails to offer any support for such a requirement. Patent Owner’s citation to its own Patent Owner Response refers to a discussion of FETs used in a switching system, not to the claimed “second switch.” *See* PO Resp. 21 (citing Ex. 2022 ¶ 146). Even in that context, Dr. Steer’s cited testimony is merely that “a FET used as a switch has two states – either ON (closed) or OFF (opened); allowing all current through or preventing current from flowing.” Ex. 2022 ¶ 146. Patent Owner’s argument that the claimed “switch” requires permitting *bidirectional* current flow in a closed state is

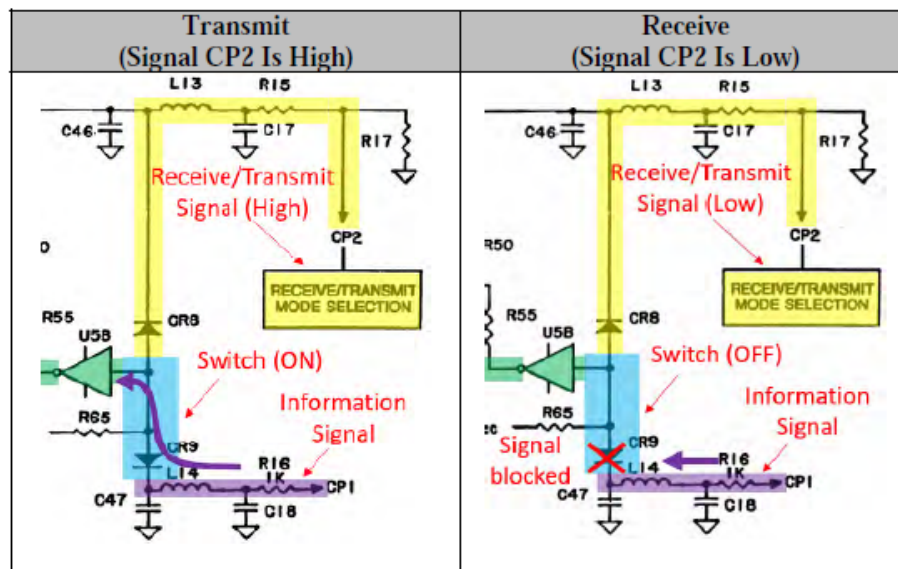
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therefore entirely unsupported. On the contrary, Dr. Steer himself testifies that “[i]n circuits, information can be conveyed either as charge, voltage, or current,” and that “a voltage signal refers to information that is almost entirely conveyed as a voltage.” Ex. 2022 ¶¶ 14–15 n.3, 42. Dr. Steer’s testimony supports that a switch may open and close a circuit for a voltage signal, not just a current signal or for bidirectional flow.

Patent Owner’s argument also lacks support because, as Petitioner points out, Patent Owner has previously argued and Dr. Steer has explained in his textbook, that diodes, at least in certain configurations, operate as switches. *See* Pet. Reply 24–27 (citing Ex. 1040, 12–13; Ex. 1038, 174–75). Patent Owner’s arguments distinguishing these prior statements as relating to different circuit configurations are based on differences that are immaterial to Petitioner’s contentions. *See* PO Sur-reply 18 n.9 (seeking to distinguish diodes from PIN diodes) (citing Ex. 1038, 178), 22–25 (referring to diodes disclosed in the ’551 patent as “rectifiers” in order to distinguish them from diodes).

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Petitioner's annotated versions of Figure 2a of Downey are reproduced below.



Pet. Reply 22. Petitioner's annotations of Figure 2a show Petitioner's argument that Downey's diode CR9 (highlighted in blue) opens and closes a circuit between inverter U5B (highlighted in green) and CP1 (highlighted in purple). *Id.* at 21–24. Downey discloses that the “input data stream is conditioned . . . and is applied to the input of inverter USB through diode CR9. Diode CR9 is forward biased by  $V_{cc}$  applied through resistor R65.” Ex. 1003, 3:27–31 (emphasis added). In view of Downey's disclosure, Dr. van der Weide testifies that “based on whether receive/transmit signal CP2 is high or low, diode CR9 either closes the circuit from CP1 to the inverter (allowing information signal CP1 to be applied to the inverter (green) through the diode CR9) or opens that circuit (preventing information signal CP1 from being applied to the inverter (green) through the diode CR9).” Ex. 1030 ¶ 37 (citing Ex. 1003, 3:27–30). He further testifies as to how CR9 allows information signal CP1 to be applied to the input of

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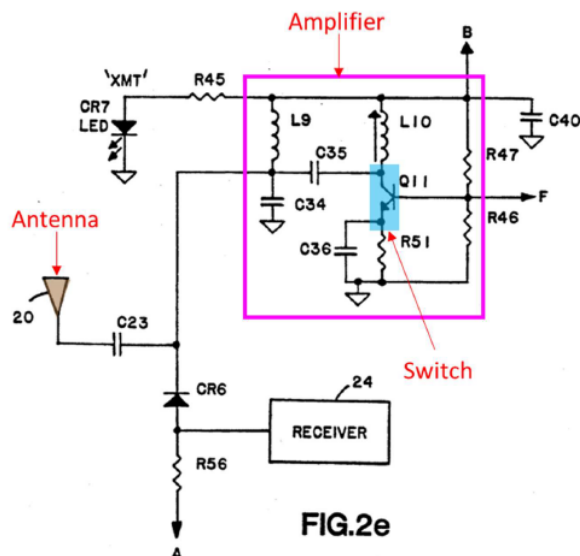
inverter U5B in the transmit mode. *See id.* ¶¶ 32–36. We credit Dr. van der Weide’s testimony because it is consistent with Downey’s disclosure of how its circuit operates.

Based on the full record before us, we find Petitioner’s argument and evidence persuasive to show that Downey’s diode CR9 teaches the recited “second switch” because Petitioner establishes sufficiently that Downey’s diode CR9 is “an electronic device for opening and closing a circuit.”

Accordingly, we find that Downey teaches or suggests this limitation.

*d) Element [1C]: “wherein said signal is transmitted by an antenna connected to a third switch”*

Petitioner contends that Downey teaches this limitation. Pet. 61 (citing Ex. 1002 ¶ 102). Petitioner’s annotated version of Figure 2e of Downey is reproduced below.



*Id.* at 64. Figure 2e is a schematic diagram of Downey’s power amplifier circuit (Ex. 1003, 2:37–38), which Petitioner has annotated to identify an amplifier, a switch (Q11), and an antenna (numeral 20). *Id.* (citing Ex. 1002 ¶ 112). Petitioner contends that Downey’s “amplifier includes a third

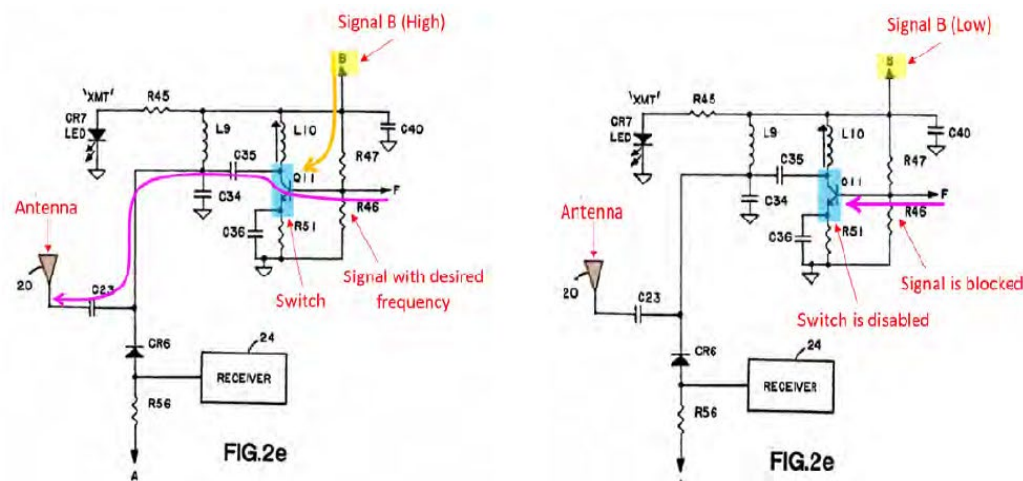
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switch—transistor Q11 (light blue . . .)—that controls whether the antenna (brown) transmits the signal.” *Id.* at 63 (citing Ex. 1003, 4:33–35, Fig. 2e; Ex. 1002 ¶ 112). Petitioner contends that “[w]hen the Downey transceiver is in the ‘transmit mode,’ current is supplied to the switch (transistor Q11), which permits the desired harmonic to be amplified and supplied to antenna 20.” *Id.* at 64–65 (citing Ex. 1003, 3:46–52, 4:35–37; Ex. 1002 ¶ 113).

Patent Owner responds that “the proper construction of ‘switch’ is [‘]an electronic device for opening and closing a circuit as dictated by an independent control input,’” and transistor Q11 in Downey is not toggled between an open and closed state, but instead is configured to operate as a “power amplifier,” providing gain. PO Resp. 52–54 (citing Ex. 1003, 3:5–8; Ex. 2022 ¶¶ 207–209).

In its Reply, Petitioner asserts that Patent Owner’s argument that Q11 is not a switch is based on Patent Owner’s characterization of Signal B as a fixed supply voltage. Pet. Reply 27–29 (citing PO Resp. 43, 53). Petitioner contends that “Signal B is a version of the receive/transmit signal CP2 transmitted from low pass filter 10 (shown in Figure 2a),” and selectively supplies power to Q11 based on whether CP2 is high or low. *Id.* at 29 (citing Ex. 1003, 3:38–52, 4:33–42; Ex. 1030 ¶¶ 47–54). Petitioner’s annotated versions of Figure 2e of Downey are reproduced below.

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Pet. Reply 30–31. Petitioner annotates Figure 2e of Downey separately to show how Downey’s circuit operates when Signal B is high and when Signal B is low. *Id.* (citing Ex. 1003, Fig. 2e; Ex. 1030 ¶¶ 47–54). Petitioner contends that depending on the state of Signal B, transistor Q11 either passes or blocks Signal F, which is the up-converted signal to be transmitted. *Id.* at 30. Petitioner contends that when Signal B is high, transistor Q11 closes the circuit between Signal F and the antenna, allowing Signal F to be amplified by transistor Q11 and transmitted by the antenna, and when Signal B is low, transistor Q11 opens the circuit between signal F and the antenna, preventing Signal F from passing through the circuit to the antenna. *Id.* Moreover, Petitioner further contends that a person of ordinary skill in the art would have understood that when Signal B is high, transistor Q11 would act as a switching amplifier by opening and closing a circuit (the circuit between inductor L10 and resistor R51) based on the value of Signal F. *Id.* at 31–32 (citing Ex. 1031, 116, 153; Ex. 1030 ¶¶ 55–58).

Patent Owner responds that transistor Q11 is only operational when the Downey transceiver is in the transmit mode, and “[i]n this mode, transistor Q11 provides gain (i.e., amplifies a signal) . . . and, thus, is

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configured to operate as a ‘power amplifier.’” PO Sur-reply 25–26 (citing Ex. 1003, 3:5–8; Ex. 2022 ¶ 207). Patent Owner contends that when the circuit is non-operational, i.e., when Signal B is low, transistor Q11 is still a power amplifier but is not working. *Id.* at 26. According to Patent Owner, “[w]hether the circuit is operational or non-operational does not change the fundamental nature of transistor Q11 as being configured as a power amplifier (i.e., it does not turn an amplifier into a switch).” *Id.*

We agree with Petitioner that Patent Owner confuses Petitioner’s contentions. Pet. Reply 31 (citing PO Resp. 53). By considering the operation of transistor Q11 in the transmit mode *only*, i.e., when Signal B is high, Patent Owner ignores Petitioner’s contention that in receive mode (when Signal B is low), transistor Q11 is off, and those two states, Petitioner contends, demonstrate that Q11 functions as a switch. *Id.*; *see also* Tr. 29:18–30:5 (providing a light switch analogy).

Dr. van der Weide testifies that Signal B corresponds to the receive/transmit signal CP2, which is generated within the low pass filter 10 portion of the transceiver. Ex. 1030 ¶¶ 49–51 (citing Ex. 1003, Fig. 2a).

Dr. van der Weide further testifies that

Since Signal B selectively supplies power to the power amplifier, it dictates whether transistor Q11 opens or closes a circuit to pass Signal F, which is the up-converted signal to be transmitted via the antenna. That is, in transmit mode, Signal B is high and transistor Q11 closes a circuit, allowing signal F to pass to the antenna. In receive mode, Signal B is low and transistor Q11 is opens a circuit and prevents signal F from passing to the antenna.

*Id.* ¶ 52 (citing Ex. 1003, 3:38–52, 4:33–42); *see also id.* ¶¶ 53, 54 (annotating Downey’s Fig. 2e showing signal F when Signal B is high and when Signal B is low). Dr. van der Weide’s testimony is consistent with Downey’s disclosure.

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We are also persuaded by Petitioner’s argument that transistor Q11 functions as a “switching amplifier.” Pet. Reply 28. Patent Owner asserts transistor Q11 is configured as an amplifier, and therefore, cannot also be configured as a switch. PO Resp. 52–53. Dr. Steer testifies in support of Patent Owner’s argument that “unlike a transistor used as a switch, transistor Q11 provides gain.” See Ex. 2022 ¶¶ 205–207. As Petitioner points out, Dr. Steer’s textbook, on the other hand, makes clear that amplifiers and switches are not mutually exclusive. See Pet. Reply 11–12 (citing Ex. 1031, 116–22; Ex. 1035, 174). For example, Dr. Steer explains in his textbook that “a switching amplifier is ideally either fully on or fully off,” i.e., functions as a switch. See Ex. 1031, 119. Dr. Steer further explains that “[t]he main concept of the Class D [switching] amplifier is using the transistor as a switch.”<sup>17</sup> *Id.*

Dr. van der Weide persuasively testifies that a person of ordinary skill in the art would have understood “that a given device (such as the transistor in an inverter) can and typically does act as both a switch and an amplifier,” and a person of ordinary skill in the art “would have been aware of specific, well-known examples of transistors used for both functions.” Ex. 1030 ¶ 11 (citing Ex. 1031, 116–22; Ex. 1035, 174).

In light of the discussion above, including Dr. van der Weide’s testimony, we agree with Petitioner that transistor Q11 functions as a switch

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<sup>17</sup> Patent Owner contends that Petitioner’s reliance on Dr. Steer’s textbook is improper as it was published well after the priority date of the ’108 patent. PO Sur-reply 16. We consider Dr. Steer’s textbook not as prior art, but instead as impeachment evidence for Dr. Steer’s testimony, which testimony is the only evidentiary support for Patent Owner’s argument that an amplifier cannot also function as a switch. See Pet. Reply 11 (refuting Dr. Steer’s testimony with Dr. Steer’s textbook).

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in Downey’s power amplifier circuit, and based on the full record before us, we find Petitioner’s argument and evidence persuasive to show that Downey’s transistor Q11 teaches the recited “third switch.”<sup>18</sup> Accordingly, we find that Downey teaches or suggests this limitation.

## 2. *Independent Claim 12*

Petitioner contends that “claim 12 has substantially the same scope as claim 1 but is the ‘method version’ of claim 1,” and relies on its arguments directed to claim 1.<sup>19</sup> Pet. 84–85 (citing 1002 ¶ 145). Patent Owner does not present separate arguments as to claim 12. *See* PO Resp. 46 n.8 (“[Patent Owner’s] analysis of claim 1 of the ’108 patent similarly applies to claim 12.”). Based on the entirety of the record and for the reasons explained by Petitioner, we determine that Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches the claim limitations recited in claim 12.

## 3. *Weighing the Graham Factors*

“Once all relevant facts are found, the ultimate legal determination [of obviousness] involves the weighing of the fact findings to conclude whether the claimed combination would have been obvious to an ordinary artisan.”

*Arctic Cat Inc. v. Bombardier Recreational Prods. Inc.*, 876 F.3d 1350, 1361

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<sup>18</sup> To the extent Patent Owner’s arguments are based on its proposed construction of the term “switch” (PO Resp. 52; Tr. 41:4–9), we do not adopt that construction and, thus, for this additional reason, we do not agree with those arguments.

<sup>19</sup> Petitioner notes that “claim 12 has essentially the same limitations as claim 1, except that the ‘first switch’ routes the signal to the antenna,” and is “a switch controlling whether the antenna transmits said signal.” Pet. 61 n.6; *see also* PO Resp. 46 n.8 (agreeing that “claim 12 also recites a first and third switch, but their roles are reversed from claim 1”).

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(Fed. Cir. 2017). On balance, considering the record before us, Petitioner has shown, by a preponderance of the evidence, that the combination of Downey and Sedra would have rendered the subject matter of claims 1 and 12 obvious to one of ordinary skill in the art at the time of the invention.

*F. Obviousness of Dependent Claims 6–9 and 17–20 over Downey, Sedra, and Hahnel*

Petitioner contends that claims 6–9 and 17–20 are unpatentable as obvious over Downey, Sedra, and Hahnel. Pet. 67–85. Patent Owner argues that Petitioner’s proposed obviousness combination fails to provide an adequate rationale to combine Downey and Hahnel given the differences between Downey’s circuit and that of Hahnel. PO Resp. 45–49. On the complete record, we are persuaded by Petitioner’s explanations and evidence in support of the obviousness ground for claims 6–9 and 17–20 over the combination of Downey, Sedra, and Hahnel. We address below the evidence, analysis, and arguments presented by the parties.

*1. Claim 6*

Claim 6 depends from claim 1 and additionally recites “a pulse shaper; and an oscillating signal generator.” Ex. 1001, 66:13–14. Petitioner contends that Downey in view of Sedra and Hahnel renders claim 6 obvious. Pet. 67.

*a) “a pulse shaper”*

Petitioner contends that Hahnel discloses the claimed “pulse shaper.” *Id.* at 70 (citing Ex. 1002 ¶¶ 124–125). Petitioner contends that the pulse shaper in Hahnel receives an oscillating signal and shapes that signal into a string of pulses. *Id.* at 72–73 (citing Ex. 1005, 2:23–29, Figs. 2C, 2D; Ex. 1002 ¶¶ 126–128).

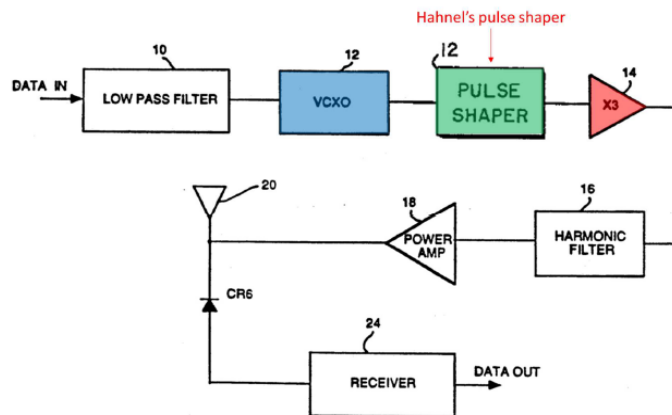
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*b) Rationale to Combine Downey and Hahnel*

Petitioner contends that a person of ordinary skill in the art would have been motivated to combine Hahnel's pulse shaper with Downey's system. *Id.* at 76 (citing Ex. 1002 ¶ 133). Specifically, Petitioner contends that both Downey and Hahnel "describe techniques to increase, or multiply, the frequency of a signal" and "Hahnel describes the benefit of using a pulse shaper in systems such as Downey," which require additional time or steps to produce an up-converted signal with sufficient amplitude without a pulse shaper. *Id.* at 76–77 (citing Ex. 1003, 2:9–11; Ex. 1005, 1:18–39; Ex. 1002 ¶ 134). Petitioner argues that combining Downey with Hahnel to use a pulse shaper in Downey's system would solve these problems yielding predictable benefits. *Id.* at 77 (citing Ex. 1002 ¶ 135). Petitioner contends that a person of ordinary skill in the art would have had a reasonable expectation of success combining Downey with Hahnel because Hahnel shows how to combine the references by "instruct[ing] that the pulse shaper should be positioned between the oscillator and frequency multiplier." *Id.* at 77–78 (citing Ex. 1005, Fig. 1; Ex. 1002 ¶ 136).

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Figure 1 of Downey, as modified and annotated by Petitioner, is reproduced below.



*Id.* at 79. Petitioner's modified Figure 1 shows Petitioner's proposal to add Hahnel's pulse shaper (green) to Downey between oscillator 12 (blue) and frequency multiplier 14 (red). *Id.* at 78–79 (citing Ex. 1002 ¶ 137).

*(1) Patent Owner's Arguments on Motivation to Combine Downey and Hahnel*

Patent Owner responds that communications systems disclosed in Downey and Hahnel are incompatible because Hahnel discloses an apparatus which produces a discontinuous radio frequency signal while Downey teaches outputting a continuous radio signal, and a person of ordinary skill in the art would not have been motivated to combine the two. PO Resp. 54 (citing Ex. 2022 ¶ 210). Patent Owner, quoting from a different Hahnel reference, argues that “[t]he circuit of Hahnel is an oscillator that is turned on and off, that is keyed, by pulses . . . [derived from a] crystal-controlled fundamental frequency.” *Id.* (citing Ex. 2018, 78).<sup>20</sup> Patent Owner argues

<sup>20</sup> Exhibit 2018 is an article titled “Multichannel Crystal Control of VHF and UHF Oscillators” by Alwin Hahnel, from the Proceedings of the Institute of Radio Engineers.

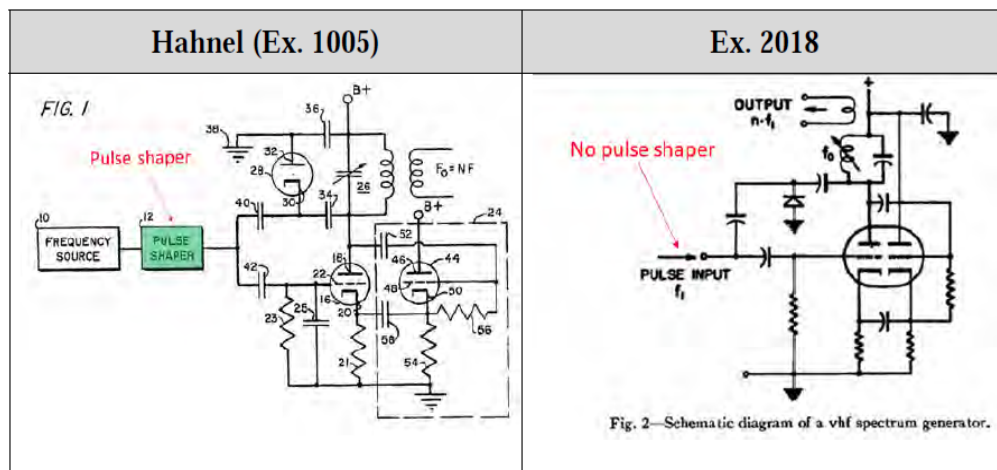
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that “Downey, on the other hand, uses a crystal to control the oscillating frequency of the RF signal,” and that “Downey specifically teaches that the benefit of its system is ‘leaving the transmit oscillator on all the time.’” *Id.* at 55 (citing Ex. 1003, 1:63). Patent Owner contends that it would not have been obvious to a person of ordinary skill in the art “to insert the pulse shaper of Hahnel into the transceiver circuit of Downey,” and that “to get to the invention of the ’474 [sic] patent using Downey and Hahnel, one would have to ignore all of the disclosure in Downey, and abandon all of the teachings and suggestions of Downey.” *Id.* (citing Ex. 2022 ¶ 212).

*(2) Petitioner’s Reply Arguments*

In its Reply, Petitioner contends that Patent Owner’s argument focuses on the wrong Hahnel reference, and that Hahnel and Exhibit 2018 are different publications that disclose different circuits, including “different components—most importantly, Exhibit 2018 does not even include the ‘pulse shaper’ for which the Petition relied on Hahnel in the first place.” Pet. Reply 33–34 (citing Ex. 1005, Fig. 1; Ex. 2018, Fig. 2; Ex. 2022 ¶¶ 188–189; Ex. 1030 ¶ 60). Petitioner’s comparison of the two circuits is reproduced below.

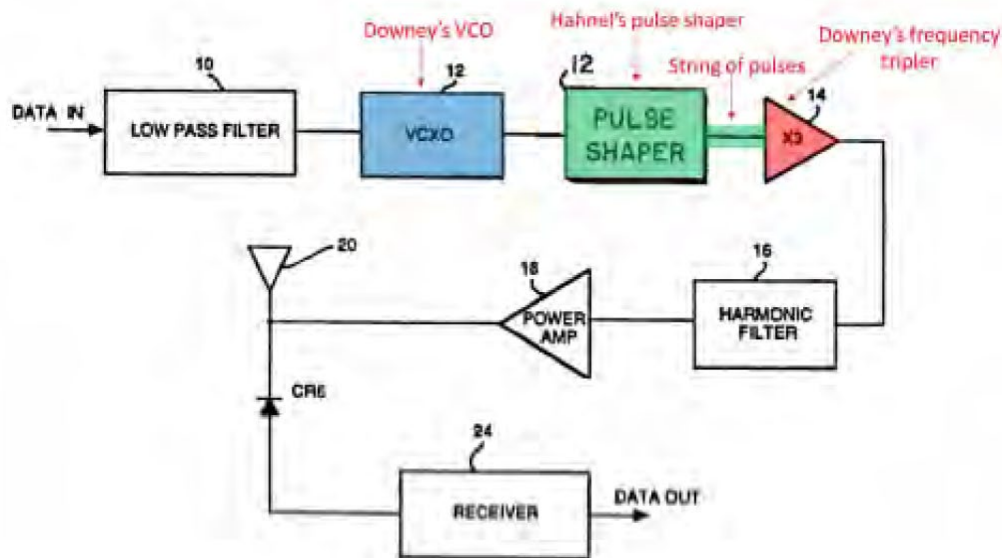
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*Id.* at 34. Petitioner annotates Figure 1 from Hahnel to highlight the pulse shaper component (green) that Petitioner relies on for the proposed combination and annotates Figure 2 of Exhibit 2018 to show that there is no pulse shaper component disclosed.

Petitioner further contends that Patent Owner's substantive arguments concerning motivation to combine are also wrong. Pet. Reply 34. Petitioner's annotated circuit combining the pulse shaper of Hahnel with Downey's circuit is reproduced below.

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*Id.* at 35. Petitioner's annotated figure of its proposed combined circuit illustrates Petitioner's argument that a person of ordinary skill in the art "would have been motivated to incorporate Hahnel's pulse shaper (green) into Downey's circuit between the voltage-controlled oscillator (VCXO 12 (blue)) and frequency tripler 14 (red)." *Id.* at 34–35 (citing Ex. 1030 ¶ 61). Petitioner contends that "the motivation to do so would be to open and close the inverter in the frequency tripler crisply, and thereby generating an up-converted signal that has a harmonic at the desired output frequency with a much larger and more constant amplitude as compared to the other undesired harmonics." *Id.* at 34. Contrary to Patent Owner's argument, Petitioner contends, "the proposed combination does not involve putting the pulse shaper *in front of* Downey's voltage-controlled oscillator (VCXO, blue) to turn the oscillator on and off," but instead, "the pulse shaper is provided *after the oscillator* and in front of Downey's frequency tripler (red)." *Id.* at 36. Because the pulse train is not fed into the oscillator in the proposed

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circuit, “it is entirely irrelevant that Hahnel’s oscillator turns on and off while Downey states that its oscillator stays ‘on all the time.’” *Id.*

*(3) Patent Owner’s Sur-reply Arguments*

Patent Owner responds that the circuits disclosed in Hahnel and in Exhibit 2018 “are functionally identical.” PO Sur-reply 27 (citing Ex. 2022 ¶¶ 188–190). According to Patent Owner, Exhibit 2018 shows a “pulse input” and combined with its express teachings, “e.g., ‘uhf oscillator . . . is keyed by pulses,’ ‘the pulse repetition interval (T) is divided into a regenerative and a degenerative period,’” a person of ordinary skill in the art would have understood Figure 2 of Exhibit 2018 to indicate the use of a pulse shaper. *Id.* Patent Owner further contends that “Hahnel’s pulse shaper comes *before* (or is provided in front of) the oscillator, not *after* as [Petitioner] suggests.” *Id.* at 28. Patent Owner asserts that “to get to the invention of the ’108 patent using Downey and Hahnel, one would have to ignore all of the disclosure in Hahnel, and abandon all of the teachings and suggestions of Hahnel.” *Id.* (citing Ex. 2022 ¶ 213).

*(4) Analysis*

We are persuaded that Petitioner sufficiently shows that an ordinarily skilled artisan would have had reason with rational underpinning to combine the teachings of Hahnel with Downey. Patent Owner’s reliance on Exhibit 2018 to argue that Hahnel discloses an apparatus incompatible with Downey is misplaced. As evident from Petitioner’s comparison of the figures from Hahnel and Exhibit 2018 (reproduced above), Hahnel and Exhibit 2018 disclose entirely different circuits. *Compare* Ex. 1005, Fig. 1 *with* Ex. 2018, Fig. 2; Pet. Reply 34. Dr. Steer testifies that “Hahnel was preceded by a 1953 publication (Ex. 2018) which describes the circuit in

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further detail.” Ex. 2022 ¶ 188. Dr. Steer further testifies that the circuits are identical and the functionality is identical. *Id.* ¶ 189. Dr. Steer, however, offers no support either in Hahnel or Exhibit 2018 for his conclusion. Neither of the references incorporates the other and there is no indication in either of the references that they are related. *See* Ex. 1003; Ex. 2018. Not only are the two circuits relied upon by Dr. Steer facially different in various respects (*see* comparison above), the circuit disclosed in Exhibit 2018 does not include the very pulse shaper component of Hahnel that Petitioner relies on for the proposed combination. Ex. 2018, Fig. 2. Because Dr. Steer and Patent Owner rely on Exhibit 2018 to argue that Hahnel’s circuit is incompatible with Downey’s circuit for the purposes of Petitioner’s proposed combination, we find Patent Owner’s arguments do not undermine Petitioner’s rationale to combine Downey with Hahnel. *Id.* ¶¶ 210–213; PO Resp. 54–55.

Contrary to Patent Owner’s assertions, Petitioner does rely on Hahnel’s teachings to argue why a person of ordinary skill in the art would have been motivated to combine Hahnel’s pulse shaper with Downey’s circuit. *See* Pet. 76–79. Hahnel explains the drawbacks of systems that do not have a pulse shaper, including “a large number of stages,” the difficulty in obtaining “a high degree of frequency accuracy,” and the difficulty in isolating “the desired harmonic frequencies from the many spurious oscillations and unwanted harmonics.” Ex. 1005, 1:18–39. Hahnel further explains its goals of providing a system, using a pulse shaper, that “permits better control of the amplitude of the desired output harmonic frequency,” and “wherein the amplitude of the desired harmonic frequency is at a maximum.” *Id.* at 1:50–2:14. Relying on that disclosure, Dr. van der Weide

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testifies that adding Hahnel’s pulse shaper to Downey’s system would yield predictable benefits, such as providing an improved up-conversion circuit that generates a signal with a sufficient amplitude and can generate such a signal with fewer steps in less time. Ex. 1003 ¶ 135 (quoting Ex. 1005, 1:18–39, 1:50–2:14). Dr. van der Weide further testifies that Hahnel expressly discloses how to combine the references because it notes that the pulse shaper should be located between an oscillator and a frequency multiplier. *Id.* ¶ 136 (citing Ex. 1005, Fig. 1). We credit Dr. van der Weide’s testimony because it is based on the express teachings of Hahnel and Downey. And because Petitioner’s proposed combination adds Hahnel’s pulse shaper *after* oscillator 12 in Downey’s circuit (*see* Petitioner’s annotated figure above), Patent Owner’s argued difference between the oscillators in Downey and Hahnel does not apply to Petitioner’s proposed use of Hahnel’s pulse shaper in Downey’s circuit. *See* Pet. Reply 36.

Based on the entirety of the record, we determine that Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches the “pulse shaper” limitation.

*c) “an oscillating signal generator”*

Claim 6 also recites “an oscillating signal generator.” Ex. 1001, 66:13–14. Petitioner contends that Downey discloses a voltage controlled oscillator, i.e., VCXO 12 that generates a modulated oscillating signal. Pet. 79 (citing Ex. 1003, 2:60–63, Fig. 1; Ex. 1002 ¶ 138). Patent Owner does not present arguments as to this limitation. *See generally* PO Resp. Based on the entirety of the record and for the reasons explained by Petitioner, we

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determine that Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches this claim limitation.

*2. Claim 7–9 and 17–20*

Claim 7 depends from claim 6 and additionally recites “wherein the oscillating signal generator comprises a voltage controlled oscillator configured to generate an oscillating signal.” Ex. 1001, 66:15–17. For the additional limitations in claim 7, Petitioner relies on its arguments directed to claim 6. Pet. 80 (citing Ex. 1003, 2:60–63, 3:61–66; Ex. 1002 ¶ 139).

Claim 8 depends from claim 7 and additionally recites “wherein the pulse shaper is configured to generate a string of pulses based on the oscillating signal.” Ex. 1001, 66:18–20. Petitioner contends that Hahnel teaches the additional limitations of claim 8 because it “discloses a pulse shaper” that “receives an oscillating signal from the frequency source and outputs a string of pulses.” Pet. 80–81 (citing Ex. 1005, 1:60–66, 2:23–30, 2:32–39, Figs. 2C, 2D; Ex. 1003, 2:60–3:2, 3:53–4:19; Ex. 1002 ¶ 140).

Claim 9 depends from claim 8 and additionally recites “wherein the first switch opens and closes based on the string of pulses.” Ex. 1001, 66:22–23. For the additional limitations of claim 9, Petitioner relies on its arguments directed to claim 1 with respect to the “first switch,” and further contends Hahnel teaches a “pulsed-signal from the pulse shaper . . . is input to the control input 22 of the switch 16.” See Pet. 82–83 (citing Ex. 1005, 1:70–2:5, 2:43–3:44, Figs. 1, 2; Ex. 1003, 4:8–13, Fig. 1; Ex. 1002 ¶ 143). Petitioner contends that in the combination of Downey, Sedra, and Hahnel, “[w]hen Downey’s inverter is implemented with Sedra’s switch, the string of pulses from Hahnel’s pulse shaper will open and close Sedra’s switch.” *Id.* at 83–84 (citing Ex. 1004, 908; Ex. 1002 ¶ 144).

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Petitioner contends that “claims 17–20 have essentially the same scope as claims 6–9, respectively,” and relies on its arguments directed to claims 6–9. Pet. 85 (citing Ex. 1002 ¶ 146).

Patent Owner does not present arguments as to claims 7–9 and 17–20. *See generally* PO Resp. Based on the entirety of the record and for the reasons explained by Petitioner, we determine that Petitioner has proved by a preponderance of the evidence that the asserted prior art teaches the claim limitations recited in those dependent claims.

### 3. *Weighing the Graham Factors*

“Once all relevant facts are found, the ultimate legal determination [of obviousness] involves the weighing of the fact findings to conclude whether the claimed combination would have been obvious to an ordinary artisan.” *Arctic Cat Inc.*, 876 F.3d at 1361. On balance, considering the record before us, Petitioner has shown, by a preponderance of the evidence, that the combination of Downey, Sedra and Hahnel would have rendered the subject matter of claims 6–9 and 17–20 obvious to one of ordinary skill in the art at the time of the invention.

## IV. PETITIONER’S OBJECTION TO PATENT OWNER’S DEMONSTRATIVES

At the oral hearing, Petitioner objected to Patent Owner’s demonstratives 81 and 82 (*see* Paper 30) as containing new arguments that were not previously presented by Patent Owner. Tr. 6:17–7:1. Petitioner argued that those demonstratives contain testimony from Dr. van der Weide that Patent Owner did not cite in its Sur-reply and address an issue that was not presented in Patent Owner’s Response. *Id.* Patent Owner did not rely on those demonstratives during the oral hearing. *Id.* at 8:10–15 (Patent

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Owner's counsel stating that he may not refer to those demonstratives during the hearing). We therefore dismiss Petitioner's objection as moot.<sup>21</sup>

## V. CONCLUSION

For the reasons discussed above, Petitioner has demonstrated, by a preponderance of the evidence, that claims 1, 6–9, 12, and 17–20 of the '108 patent are unpatentable.<sup>22</sup> Our conclusions regarding the challenged claims are summarized below:

<b>Claims Challenged</b>	<b>35 U.S.C. §</b>	<b>Reference(s)/ Basis</b>	<b>Claims Shown Unpatentable</b>	<b>Claims Not Shown Unpatentable</b>
1, 12	103(a)	Downey, Sedra	1, 12	
6–9, 17–20	103(a)	Downey, Sedra, Hahnel	6–9, 17–20	
<b>Overall Outcome</b>			1, 6–9, 12, 17–20	

<sup>21</sup> We also note that demonstratives are not evidence, and in making our decision, we consider the arguments presented in the papers and the evidence presented in the exhibits filed in this case. *See* Paper 29, 5 (“Demonstrative exhibits used at the hearing are not evidence, nor will they be relied upon as evidence.”); Consolidated Trial Practice Guide 84, available at <https://www.uspto.gov/TrialPracticeGuideConsolidated> (“Demonstrative exhibits used at the final hearing are aids to oral argument and not evidence.”).

<sup>22</sup> Should Patent Owner wish to pursue amendment of the challenged claims in a reissue or reexamination proceeding subsequent to the issuance of this decision, we draw Patent Owner's attention to the April 2019 *Notice Regarding Options for Amendments by Patent Owner Through Reissue or Reexamination During a Pending AIA Trial Proceeding*. *See* 84 Fed. Reg. 16,654 (Apr. 22, 2019). If Patent Owner chooses to file a reissue application or a request for reexamination of the challenged patent, we remind Patent Owner of its continuing obligation to notify the Board of any such related matters in updated mandatory notices. *See* 37 C.F.R. § 42.8(a)(3), (b)(2).

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VI. ORDER

In consideration of the foregoing, it is hereby:

ORDERED that claims 1, 6–9, 12, and 17–20 of U.S. Patent No. 8,190,108 B2 are determined to be unpatentable;

FURTHER ORDERED that Petitioner’s objection to Patent Owner’s demonstratives 81 and 82 is *dismissed* as moot; and

FURTHER ORDERED that, because this a Final Written Decision, parties to this proceeding seeking judicial review of this Decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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(12) **United States Patent**  
**Sorrells et al.**

(10) **Patent No.:** **US 8,190,108 B2**  
(45) **Date of Patent:** **May 29, 2012**

(54) **METHOD AND SYSTEM FOR FREQUENCY UP-CONVERSION**

(56) **References Cited**

(75) Inventors: **David F. Sorrells**, Middleburg, FL (US); **Michael J. Bultman**, Jacksonville, FL (US); **Robert W. Cook**, Switzerland, FL (US); **Richard C. Looke**, Jacksonville, FL (US); **Charley D. Moses, Jr.**, DeBary, FL (US)

U.S. PATENT DOCUMENTS  
2,057,613 A 10/1936 Gardner  
(Continued)

**FOREIGN PATENT DOCUMENTS**

DE 1936252 1/1971  
(Continued)

**OTHER PUBLICATIONS**

Aghvami, H. et al., "Land Mobile Satellites Using the Highly Elliptic Orbits—The UK T-SAT Mobile Payload," *Fourth International Conference on Satellite Systems for Mobile Communications and Navigation*, IEE, pp. 147-153 (Oct. 17-19, 1988).

(Continued)

(73) Assignee: **ParkerVision, Inc.**, Jacksonville, FL (US)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/093,887**

*Primary Examiner* — Sam Bhattacharya  
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(22) Filed: **Apr. 26, 2011**

(57) **ABSTRACT**

(65) **Prior Publication Data**

US 2011/0255578 A1 Oct. 20, 2011

**Related U.S. Application Data**

(60) Continuation of application No. 12/435,595, filed on May 5, 2009, now Pat. No. 8,019,291, which is a continuation of application No. 11/802,389, filed on May 22, 2007, now Pat. No. 7,546,096, which is a division of application No. 10/086,367, filed on Mar. 4, 2002, now Pat. No. 7,236,754, which is a continuation of application No. 09/379,497, filed on Aug. 23, 1999, now Pat. No. 6,353,735, which is a continuation of application No. 09/176,154, filed on Oct. 21, 1998, now Pat. No. 6,091,940.

(51) **Int. Cl.**  
**G06F 15/16** (2006.01)

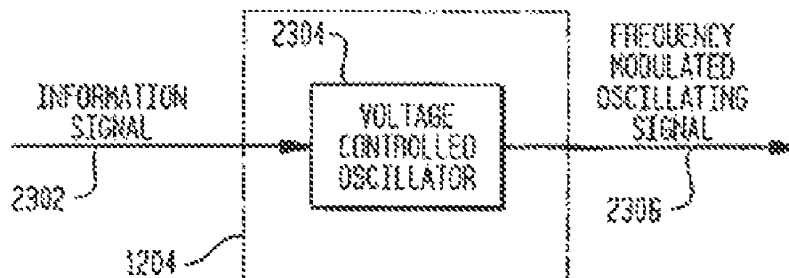
(52) **U.S. Cl.** ..... **455/118; 455/69**

(58) **Field of Classification Search** ..... 455/69,  
455/76, 78, 82-84, 118

See application file for complete search history.

A method and system is described wherein a signal with a lower frequency is up-converted to a higher frequency. In one embodiment, the higher frequency signal is used as a stable frequency and phase reference. In another embodiment, the invention is used as a transmitter. The up-conversion is accomplished by controlling a switch with an oscillating signal, the frequency of the oscillating signal being selected as a sub-harmonic of the desired output frequency. When the invention is being used as a frequency or phase reference, the oscillating signal is not modulated, and controls a switch that is connected to a bias signal. When the invention is being used in the frequency modulation (FM) or phase modulation (PM) implementations, the oscillating signal is modulated by an information signal before it causes the switch to gate the bias signal. In the amplitude modulation implementation (AM), the oscillating signal is not modulated, but rather causes the switch to gate a reference signal that is substantially equal to or proportional to the information signal. In the FM and PM implementations, the signal that is output from the switch is modulated substantially the same as the modulated oscillating signal. In the AM implementation, the signal that is output from the switch has an amplitude that is a function of the information signal. In both embodiments, the output of the switch is filtered, and the desired harmonic is output.

**21 Claims, 59 Drawing Sheets**



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## U.S. PATENT DOCUMENTS

2,241,078 A	5/1941	Vreeland	4,066,919 A	1/1978	Huntington
2,270,385 A	1/1942	Skillman	4,080,573 A	3/1978	Howell
2,283,575 A	5/1942	Roberts	4,081,748 A	3/1978	Batz
2,358,152 A	9/1944	Earp	4,115,737 A	9/1978	Hongu et al.
2,410,350 A	10/1946	Labin et al.	4,130,765 A	12/1978	Arakelian et al.
2,451,430 A	10/1948	Barone	4,130,806 A	12/1978	Van Gerwen et al.
2,462,069 A	2/1949	Chatterjea et al.	4,132,952 A	1/1979	Hongu et al.
2,462,181 A	2/1949	Grosselfinger	4,142,155 A	2/1979	Adachi
2,472,798 A	6/1949	Fredendall	4,143,322 A	3/1979	Shimamura
2,497,859 A	2/1950	Boughtwood et al.	4,145,659 A	3/1979	Wolfram
2,499,279 A	2/1950	Peterson	4,158,149 A	6/1979	Otofuji
2,530,824 A	11/1950	King	4,170,764 A	10/1979	Salz et al.
2,802,208 A	8/1957	Hobbs	4,173,164 A	11/1979	Adachi et al.
2,985,875 A	5/1961	Grisdale et al.	4,204,171 A	5/1980	Sutphin, Jr.
3,023,309 A	2/1962	Foulkes	4,210,872 A	7/1980	Gregorian
3,069,679 A	12/1962	Sweeney et al.	4,220,977 A	9/1980	Yamanaka
3,104,393 A	9/1963	Vogelman	4,241,451 A	12/1980	Maixner et al.
3,114,106 A	12/1963	McManus	4,245,355 A	1/1981	Pascoe et al.
3,118,117 A	1/1964	King et al.	4,250,458 A	2/1981	Richmond et al.
3,226,643 A	12/1965	McNair	4,253,066 A	2/1981	Fisher et al.
3,246,084 A	4/1966	Kryter	4,253,067 A	2/1981	Caples et al.
3,258,694 A	6/1966	Shepherd	4,253,069 A	2/1981	Nossek
3,383,598 A	5/1968	Sanders	4,286,283 A	8/1981	Clemens
3,384,822 A	5/1968	Miyagi	4,308,614 A	12/1981	Fisher et al.
3,454,718 A	7/1969	Perreault	4,313,222 A	1/1982	Katthän
3,523,291 A	8/1970	Pierret	4,320,361 A	3/1982	Kikkert
3,548,342 A	12/1970	Maxey	4,320,536 A	3/1982	Dietrich
3,555,428 A	1/1971	Perreault	4,334,324 A	6/1982	Hoover
3,614,627 A	10/1971	Runyan et al.	4,346,477 A	8/1982	Gordy
3,614,630 A	10/1971	Rorden	4,355,401 A	10/1982	Ikoma et al.
3,617,892 A	11/1971	Hawley et al.	4,356,558 A	10/1982	Owen et al.
3,617,898 A	11/1971	Janning, Jr.	4,360,867 A	11/1982	Gonda
3,621,402 A	11/1971	Gardner	4,363,132 A	12/1982	Collin
3,622,885 A	11/1971	Kruszynski et al.	4,363,976 A	12/1982	Minor
3,623,160 A	11/1971	Giles et al.	4,365,217 A	12/1982	Berger et al.
3,626,315 A	12/1971	Stirling et al.	4,369,522 A	1/1983	Cerny, Jr. et al.
3,626,417 A	12/1971	Gilbert	4,370,572 A	1/1983	Cosand et al.
3,629,696 A	12/1971	Bartelink	4,380,828 A	4/1983	Moon
3,643,168 A	2/1972	Manicki	4,384,357 A	5/1983	deBuda et al.
3,662,268 A	5/1972	Gans et al.	4,389,579 A	6/1983	Stein
3,689,841 A	9/1972	Bello et al.	4,392,255 A	7/1983	Del Giudice
3,694,754 A	9/1972	Baltzer	4,393,352 A	7/1983	Volpe et al.
3,702,440 A	11/1972	Moore	4,393,395 A	7/1983	Hacke et al.
3,714,577 A	1/1973	Hayes	4,405,835 A	9/1983	Jansen et al.
3,716,730 A	2/1973	Cerny, Jr.	4,409,877 A	10/1983	Budelman
3,717,844 A	2/1973	Barret et al.	4,430,629 A	2/1984	Betzl et al.
3,719,903 A	3/1973	Goodson	4,439,787 A	3/1984	Mogi et al.
3,735,048 A	5/1973	Tomsa et al.	4,441,080 A	4/1984	Saari
3,736,513 A	5/1973	Wilson	4,446,438 A	5/1984	Chang et al.
3,737,778 A	6/1973	Van Gerwen et al.	4,456,990 A	6/1984	Fisher et al.
3,739,282 A	6/1973	Bruch et al.	4,463,320 A	7/1984	Dawson
3,740,636 A	6/1973	Hogrefe et al.	4,470,145 A	9/1984	Williams
3,764,921 A	10/1973	Huard	4,472,785 A	9/1984	Kasuga
3,767,984 A	10/1973	Shinoda et al.	4,479,226 A	10/1984	Prabhu et al.
3,806,811 A	4/1974	Thompson	4,481,490 A	11/1984	Huntley
3,809,821 A	5/1974	Melvin	4,481,642 A	11/1984	Hanson
3,852,530 A	12/1974	Shen	4,483,017 A	11/1984	Hampel et al.
3,868,601 A	2/1975	MacAfee	4,484,143 A	11/1984	French et al.
3,940,697 A	2/1976	Morgan	4,485,347 A	11/1984	Hirasawa et al.
3,949,300 A	4/1976	Sadler	4,485,488 A	11/1984	Houdart
3,967,202 A	6/1976	Batz	4,488,119 A	12/1984	Marshall
3,980,945 A	9/1976	Bickford	4,504,803 A	3/1985	Lee et al.
3,987,280 A	10/1976	Bauer	4,510,467 A	4/1985	Chang et al.
3,991,277 A	11/1976	Hirata	4,517,519 A	5/1985	Mukaiyama
4,003,002 A	1/1977	Snijders et al.	4,517,520 A	5/1985	Ogawa
4,004,237 A	1/1977	Kratzer	4,518,935 A	5/1985	van Roermund
4,013,966 A	3/1977	Campbell	4,521,892 A	6/1985	Vance et al.
4,016,366 A	4/1977	Kurata	4,562,414 A	12/1985	Linder et al.
4,017,798 A	4/1977	Gordy et al.	4,563,773 A	1/1986	Dixon, Jr. et al.
4,019,140 A	4/1977	Swerdlow	4,571,738 A	2/1986	Vance
4,020,487 A	4/1977	Winter	4,577,157 A	3/1986	Reed
4,032,847 A	6/1977	Unkauf	4,583,239 A	4/1986	Vance
4,035,732 A	7/1977	Lohrmann	4,591,736 A	5/1986	Hirao et al.
4,045,740 A	8/1977	Baker	4,591,930 A	5/1986	Baumeister
4,047,121 A	9/1977	Campbell	4,596,046 A	6/1986	Richardson et al.
4,048,598 A	9/1977	Knight	4,601,046 A	7/1986	Halpern et al.
4,051,475 A	9/1977	Campbell	4,602,220 A	7/1986	Kurihara
4,066,841 A	1/1978	Young	4,603,300 A	7/1986	Welles, II et al.
			4,612,464 A	9/1986	Ishikawa et al.

## US 8,190,108 B2

Page 3

4,612,518 A	9/1986	Gans et al.	4,970,703 A	11/1990	Hariharan et al.
4,616,191 A	10/1986	Galani et al.	4,972,436 A	11/1990	Halim et al.
4,621,217 A	11/1986	Saxe et al.	4,982,353 A	1/1991	Jacob et al.
4,628,517 A	12/1986	Schwarz et al.	4,984,077 A	1/1991	Uchida
4,633,510 A	12/1986	Suzuki et al.	4,995,055 A	2/1991	Weinberger et al.
4,634,998 A	1/1987	Crawford	5,003,621 A	3/1991	Gailus
4,648,021 A	3/1987	Alberkrack	5,005,169 A	4/1991	Bronder et al.
4,651,034 A	3/1987	Sato	5,006,810 A	4/1991	Popescu
4,651,210 A	3/1987	Olson	5,006,854 A	4/1991	White et al.
4,653,117 A	3/1987	Heck	5,010,585 A	4/1991	Garcia
4,660,164 A	4/1987	Leibowitz	5,012,245 A	4/1991	Scott et al.
4,663,744 A	5/1987	Russell et al.	5,014,130 A	5/1991	Heister et al.
4,675,882 A	6/1987	Lillie et al.	5,014,304 A	5/1991	Nicollini et al.
4,688,237 A	8/1987	Brault	5,015,963 A	5/1991	Sutton
4,688,253 A	8/1987	Gumm	5,016,242 A	5/1991	Tang
4,716,376 A	12/1987	Daudelin	5,017,924 A	5/1991	Guiberteau et al.
4,716,388 A	12/1987	Jacobs	5,020,149 A	5/1991	Hemmie
4,718,113 A	1/1988	Rother et al.	5,020,154 A	5/1991	Zierhut
4,726,041 A	2/1988	Prohaska et al.	5,020,745 A	6/1991	Stetson, Jr.
4,733,403 A	3/1988	Simone	5,023,572 A	6/1991	Caldwell et al.
4,734,591 A	3/1988	Ichitsubo	5,047,860 A	9/1991	Rogalski
4,737,969 A	4/1988	Steel et al.	5,052,050 A	9/1991	Collier et al.
4,740,675 A	4/1988	Brosnan et al.	5,058,107 A	10/1991	Stone et al.
4,740,792 A	4/1988	Sagey et al.	5,062,122 A	10/1991	Pham et al.
4,743,858 A	5/1988	Everard	5,063,387 A	11/1991	Mower
4,745,463 A	5/1988	Lu	5,065,409 A	11/1991	Hughes et al.
4,751,468 A	6/1988	Agoston	5,083,050 A	1/1992	Vasile
4,757,538 A	7/1988	Zink	5,091,921 A	2/1992	Minami
4,761,798 A	8/1988	Griswold, Jr. et al.	5,095,533 A	3/1992	Loper et al.
4,768,187 A	8/1988	Marshall	5,095,536 A	3/1992	Loper
4,769,612 A	9/1988	Tamakoshi et al.	5,111,152 A	5/1992	Makino
4,771,265 A	9/1988	Okui et al.	5,113,094 A	5/1992	Grace et al.
4,772,853 A	9/1988	Hart	5,113,129 A	5/1992	Hughes
4,785,463 A	11/1988	Janc et al.	5,115,409 A	5/1992	Stepp
4,789,837 A	12/1988	Ridgers	5,122,765 A	6/1992	Pataut
4,791,584 A	12/1988	Greivenkamp, Jr.	5,124,592 A	6/1992	Hagino
4,801,823 A	1/1989	Yokoyama	5,126,682 A	6/1992	Weinberg et al.
4,806,790 A	2/1989	Sone	5,131,014 A	7/1992	White
4,810,904 A	3/1989	Crawford	5,136,267 A	8/1992	Cabot
4,810,976 A	3/1989	Cowley et al.	5,140,705 A	8/1992	Kosuga
4,811,362 A	3/1989	Yester, Jr. et al.	5,150,124 A	9/1992	Moore et al.
4,811,422 A	3/1989	Kahn	5,151,661 A	9/1992	Caldwell et al.
4,814,649 A	3/1989	Young	5,157,687 A	10/1992	Tymes
4,816,704 A	3/1989	Fiori, Jr.	5,159,710 A	10/1992	Cusdin
4,819,252 A	4/1989	Christopher	5,164,985 A	11/1992	Nysen et al.
4,833,445 A	5/1989	Buchele	5,170,414 A	12/1992	Silvian
4,841,265 A	6/1989	Watanabe et al.	5,172,019 A	12/1992	Naylor et al.
4,845,389 A	7/1989	Pyndiah et al.	5,172,070 A	12/1992	Hiraiwa et al.
4,855,894 A	8/1989	Asahi et al.	5,179,731 A	1/1993	Tränkle et al.
4,857,928 A	8/1989	Gailus et al.	5,191,459 A	3/1993	Thompson et al.
4,862,121 A	8/1989	Hochschild et al.	5,196,806 A	3/1993	Ichihara
4,866,441 A	9/1989	Conway et al.	5,204,642 A	4/1993	Asghar et al.
4,868,654 A	9/1989	Juri et al.	5,212,827 A	5/1993	Meszko et al.
4,870,659 A	9/1989	Oishi et al.	5,214,787 A	5/1993	Karkota, Jr.
4,871,987 A	10/1989	Kawase	5,218,562 A	6/1993	Basehore et al.
4,873,492 A	10/1989	Myer	5,220,583 A	6/1993	Solomon
4,885,587 A	12/1989	Wiegand et al.	5,220,680 A	6/1993	Lee
4,885,671 A	12/1989	Peil	5,222,079 A	6/1993	Rasor
4,885,756 A	12/1989	Fontanes et al.	5,222,144 A	6/1993	Whikehart
4,888,557 A	12/1989	Puckette, IV et al.	5,222,250 A	6/1993	Cleveland et al.
4,890,302 A	12/1989	Muiliwijk	5,230,097 A	7/1993	Currie et al.
4,893,316 A	1/1990	Janc et al.	5,239,496 A	8/1993	Vancraeynest
4,893,341 A	1/1990	Gehring	5,239,686 A	8/1993	Downey
4,894,766 A	1/1990	De Agro	5,239,687 A	8/1993	Chen
4,896,152 A	1/1990	Tiemann	5,241,561 A	8/1993	Barnard
4,902,979 A	2/1990	Puckette, IV	5,249,203 A	9/1993	Loper
4,908,579 A	3/1990	Tawfik et al.	5,251,218 A	10/1993	Stone et al.
4,910,752 A	3/1990	Yester, Jr. et al.	5,251,232 A	10/1993	Nonami
4,914,405 A	4/1990	Wells	5,260,970 A	11/1993	Henry et al.
4,920,510 A	4/1990	Senderowicz et al.	5,260,973 A	11/1993	Watanabe
4,922,452 A	5/1990	Larsen et al.	5,263,194 A	11/1993	Ragan
4,931,716 A	6/1990	Jovanovic et al.	5,263,196 A	11/1993	Jasper
4,931,921 A	6/1990	Anderson	5,263,198 A	11/1993	Geddes et al.
4,943,974 A	7/1990	Motamedi	5,267,023 A	11/1993	Kawasaki
4,944,025 A	7/1990	Gehring et al.	5,278,826 A	1/1994	Murphy et al.
4,955,079 A	9/1990	Connerney et al.	5,282,023 A	1/1994	Scarpa
4,965,467 A	10/1990	Bilteerijst	5,282,222 A	1/1994	Fattouche et al.
4,967,160 A	10/1990	Quievy et al.	5,287,516 A	2/1994	Schaub
4,968,958 A	11/1990	Hoare	5,293,398 A	3/1994	Hamao et al.

## US 8,190,108 B2

Page 4

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5,303,417	A	4/1994	Laws	5,500,758	A	3/1996	Thompson et al.
5,307,517	A	4/1994	Rich	5,512,946	A	4/1996	Murata et al.
5,315,583	A	5/1994	Murphy et al.	5,513,389	A	4/1996	Reeser et al.
5,319,799	A	6/1994	Morita	5,515,014	A	5/1996	Troutman
5,321,852	A	6/1994	Seong	5,517,688	A	5/1996	Fajen et al.
5,325,204	A	6/1994	Scarpa	5,519,890	A	5/1996	Pinckley
5,337,014	A	8/1994	Najle et al.	5,523,719	A	6/1996	Longo et al.
5,339,054	A	8/1994	Taguchi	5,523,726	A	6/1996	Kroeger et al.
5,339,395	A	8/1994	Pickett et al.	5,523,760	A	6/1996	McEwan
5,339,459	A	8/1994	Schiltz et al.	5,528,068	A	6/1996	Ohmi
5,345,239	A	9/1994	Madni et al.	5,535,402	A	7/1996	Leibowitz et al.
5,353,306	A	10/1994	Yamamoto	5,539,770	A	7/1996	Ishigaki
5,355,114	A	10/1994	Sutterlin et al.	5,551,076	A	8/1996	Bonn
5,361,408	A	11/1994	Watanabe et al.	5,552,789	A	9/1996	Schuermann
5,369,404	A	11/1994	Galton	5,555,453	A	9/1996	Kajimoto et al.
5,369,789	A	11/1994	Kosugi et al.	5,557,641	A	9/1996	Weinberg
5,369,800	A	11/1994	Takagi et al.	5,557,642	A	9/1996	Williams
5,375,146	A	12/1994	Chalmers	5,559,468	A	9/1996	Gailus et al.
5,379,040	A	1/1995	Mizomoto et al.	5,559,809	A	9/1996	Jeon et al.
5,379,141	A	1/1995	Thompson et al.	5,563,550	A	10/1996	Toth
5,388,063	A	2/1995	Takatori et al.	5,564,097	A	10/1996	Swanke
5,389,839	A	2/1995	Heck	5,574,755	A	11/1996	Persico
5,390,215	A	2/1995	Anita et al.	5,579,341	A	11/1996	Smith et al.
5,390,364	A	2/1995	Webster et al.	5,579,347	A	11/1996	Lindquist et al.
5,400,084	A	3/1995	Scarpa	5,584,068	A	12/1996	Mohindra
5,400,363	A	3/1995	Waugh et al.	5,589,793	A	12/1996	Kassapian
5,404,127	A	4/1995	Lee et al.	5,592,131	A	1/1997	Labreche et al.
5,410,195	A	4/1995	Ichihara	5,600,680	A	2/1997	Mishima et al.
5,410,270	A	4/1995	Rybicki et al.	5,602,847	A	2/1997	Pagano et al.
5,410,541	A	4/1995	Hotto	5,602,868	A	2/1997	Wilson
5,410,743	A	4/1995	Seely et al.	5,604,592	A	2/1997	Kotidis et al.
5,412,352	A	5/1995	Graham	5,604,732	A	2/1997	Kim et al.
5,416,449	A	5/1995	Joshi	5,606,731	A	2/1997	Pace et al.
5,416,803	A	5/1995	Janer	5,608,531	A	3/1997	Honda et al.
5,422,909	A	6/1995	Love et al.	5,610,946	A	3/1997	Tanaka et al.
5,422,913	A	6/1995	Wilkinson	RE35,494	E	4/1997	Nicollini
5,423,082	A	6/1995	Cygan et al.	5,617,451	A	4/1997	Mimura et al.
5,428,638	A	6/1995	Cioffi et al.	5,619,538	A	4/1997	Sempel et al.
5,428,640	A	6/1995	Townley	5,621,455	A	4/1997	Rogers et al.
5,434,546	A	7/1995	Palmer	5,628,055	A	5/1997	Stein
5,438,329	A	8/1995	Gastouniotis et al.	5,630,227	A	5/1997	Bella et al.
5,438,692	A	8/1995	Mohindra	5,633,610	A	5/1997	Maekawa et al.
5,440,311	A	8/1995	Gallagher et al.	5,633,815	A	5/1997	Young
5,444,415	A	8/1995	Dent et al.	5,634,207	A	5/1997	Yamaji et al.
5,444,416	A	8/1995	Ishikawa et al.	5,636,140	A	6/1997	Lee et al.
5,444,865	A	8/1995	Heck et al.	5,638,396	A	6/1997	Klimek
5,446,421	A	8/1995	Kechkaylo	5,640,415	A	6/1997	Pandula
5,446,422	A	8/1995	Mattila et al.	5,640,424	A	6/1997	Banavong et al.
5,448,602	A	9/1995	Ohmori et al.	5,640,428	A	6/1997	Abe et al.
5,449,939	A	9/1995	Horiguchi et al.	5,640,698	A	6/1997	Shen et al.
5,451,899	A	9/1995	Lawton	5,642,071	A	6/1997	Sevenhans et al.
5,454,007	A	9/1995	Dutta	5,648,985	A	7/1997	Bjerede et al.
5,454,009	A	9/1995	Fruit et al.	5,650,785	A	7/1997	Rodal
5,461,646	A	10/1995	Anvari	5,659,372	A	8/1997	Patel et al.
5,463,356	A	10/1995	Palmer	5,661,424	A	8/1997	Tang
5,463,357	A	10/1995	Hobden	5,663,878	A	9/1997	Walker
5,465,071	A	11/1995	Kobayashi et al.	5,663,986	A	9/1997	Striffler
5,465,410	A	11/1995	Hiben et al.	5,668,836	A	9/1997	Smith et al.
5,465,415	A	11/1995	Bien	5,675,392	A	10/1997	Nayebi et al.
5,465,418	A	11/1995	Zhou et al.	5,678,220	A	10/1997	Fournier
5,471,162	A	11/1995	McEwan	5,678,226	A	10/1997	Li et al.
5,471,665	A	11/1995	Pace et al.	5,680,078	A	10/1997	Ariie
5,479,120	A	12/1995	McEwan	5,680,418	A	10/1997	Croft et al.
5,479,447	A	12/1995	Chow et al.	5,682,099	A	10/1997	Thompson et al.
5,481,570	A	1/1996	Winters	5,689,413	A	11/1997	Jaramillo et al.
5,483,193	A	1/1996	Kennedy et al.	5,691,629	A	11/1997	Belnap
5,483,245	A	1/1996	Ruinet	5,694,096	A	12/1997	Ushiroku et al.
5,483,549	A	1/1996	Weinberg et al.	5,697,074	A	12/1997	Makikallio et al.
5,483,600	A	1/1996	Werrbach	5,699,006	A	12/1997	Zeile et al.
5,483,691	A	1/1996	Heck et al.	5,703,584	A	12/1997	Hill
5,483,695	A	1/1996	Pardoen	5,705,949	A	1/1998	Alelyunas et al.
5,490,173	A	2/1996	Whikehart et al.	5,705,955	A	1/1998	Freeburg et al.
5,490,176	A	2/1996	Peltier	5,710,992	A	1/1998	Sawada et al.
5,493,581	A	2/1996	Young et al.	5,710,998	A	1/1998	Opas
5,493,721	A	2/1996	Reis	5,714,910	A	2/1998	Skoczen et al.
5,495,200	A	2/1996	Kwan et al.	5,715,281	A	2/1998	Bly et al.
5,495,202	A	2/1996	Hsu	5,721,514	A	2/1998	Crockett et al.
5,495,500	A	2/1996	Jovanovich et al.	5,724,002	A	3/1998	Hulick
5,499,267	A	3/1996	Ohe et al.	5,724,041	A	3/1998	Inoue et al.

## US 8,190,108 B2

Page 5

5,724,653 A	3/1998	Baker et al.	5,903,196 A	5/1999	Salvi et al.
5,729,577 A	3/1998	Chen	5,903,421 A	5/1999	Furutani et al.
5,729,829 A	3/1998	Talwar et al.	5,903,553 A	5/1999	Sakamoto et al.
5,732,333 A	3/1998	Cox et al.	5,903,595 A	5/1999	Suzuki
5,734,683 A	3/1998	Hulkko et al.	5,903,609 A	5/1999	Kool et al.
5,736,895 A	4/1998	Yu et al.	5,903,827 A	5/1999	Kennan et al.
5,737,035 A	4/1998	Rotzoll	5,903,854 A	5/1999	Abe et al.
5,742,189 A	4/1998	Yoshida et al.	5,905,433 A	5/1999	Wortham
5,745,846 A	4/1998	Myer et al.	5,905,449 A	5/1999	Tsubouchi et al.
5,748,683 A	5/1998	Smith et al.	5,907,149 A	5/1999	Marckini
5,751,154 A	5/1998	Tsugai	5,907,197 A	5/1999	Faulk
5,757,858 A	5/1998	Black et al.	5,909,447 A	6/1999	Cox et al.
5,757,864 A	5/1998	Petranovich et al.	5,909,460 A	6/1999	Dent
5,757,870 A	5/1998	Miya et al.	5,911,116 A	6/1999	Nossowitz
RE35,829 E	6/1998	Sanderford, Jr.	5,911,123 A	6/1999	Shaffer et al.
5,760,629 A	6/1998	Urabe et al.	5,914,622 A	6/1999	Inoue
5,760,632 A	6/1998	Kawakami et al.	5,915,278 A	6/1999	Mallick
5,760,645 A	6/1998	Comte et al.	5,918,167 A	6/1999	Tiller et al.
5,764,087 A	6/1998	Clark	5,920,199 A	7/1999	Sauer
5,767,726 A	6/1998	Wang	5,926,065 A	7/1999	Wakai et al.
5,768,118 A	6/1998	Faulk et al.	5,926,513 A	7/1999	Suominen et al.
5,768,323 A	6/1998	Kroeger et al.	5,933,467 A	8/1999	Sehier et al.
5,770,985 A	6/1998	Ushiroku et al.	5,937,013 A	8/1999	Lam et al.
5,771,442 A	6/1998	Wang et al.	5,943,370 A	8/1999	Smith
5,777,692 A	7/1998	Ghosh	5,945,660 A	8/1999	Nakasuji et al.
5,777,771 A	7/1998	Smith	5,949,827 A	9/1999	DeLuca et al.
5,778,022 A	7/1998	Walley	5,952,895 A	9/1999	McCune, Jr. et al.
5,781,600 A	7/1998	Reeve et al.	5,953,642 A	9/1999	Feldtkeller et al.
5,784,689 A	7/1998	Kobayashi	5,955,992 A	9/1999	Shattil
5,786,844 A	7/1998	Rogers et al.	5,959,850 A	9/1999	Lim
5,787,125 A	7/1998	Mittel	5,960,033 A	9/1999	Shibano et al.
5,790,587 A	8/1998	Smith et al.	5,970,053 A	10/1999	Schick et al.
5,793,801 A	8/1998	Fertner	5,973,568 A	10/1999	Shapiro et al.
5,793,817 A	8/1998	Wilson	5,973,570 A	10/1999	Salvi et al.
5,793,818 A	8/1998	Claydon et al.	5,982,315 A	11/1999	Bazarjani et al.
5,801,654 A	9/1998	Traylor	5,982,329 A	11/1999	Pittman et al.
5,802,463 A	9/1998	Zuckerman	5,982,810 A	11/1999	Nishimori
5,805,460 A	9/1998	Greene et al.	5,986,600 A	11/1999	McEwan
5,809,060 A	9/1998	Cafarella et al.	5,994,689 A	11/1999	Charrier
5,812,546 A	9/1998	Zhou et al.	5,995,030 A	11/1999	Cabler
5,818,582 A	10/1998	Fernandez et al.	5,999,561 A	12/1999	Naden et al.
5,818,869 A	10/1998	Miya et al.	6,005,506 A	12/1999	Bazarjani et al.
5,825,254 A	10/1998	Lee	6,005,903 A	12/1999	Mendelovicz
5,825,257 A	10/1998	Klymyshyn et al.	6,009,317 A	12/1999	Wynn
5,834,979 A	11/1998	Yatsuka	6,011,435 A	1/2000	Takeyabu et al.
5,834,985 A	11/1998	Sundegård	6,014,176 A	1/2000	Nayebi et al.
5,834,987 A	11/1998	Dent	6,014,551 A	1/2000	Pesola et al.
5,841,324 A	11/1998	Williams	6,018,262 A	1/2000	Noro et al.
5,841,811 A	11/1998	Song	6,018,553 A	1/2000	Sanielevici et al.
5,844,449 A	12/1998	Abeno et al.	6,026,286 A	2/2000	Long
5,844,868 A	12/1998	Takahashi et al.	6,028,887 A	2/2000	Harrison et al.
5,847,594 A	12/1998	Mizuno	6,031,217 A	2/2000	Aswell et al.
5,859,878 A	1/1999	Phillips et al.	6,034,566 A	3/2000	Ohe
5,864,754 A	1/1999	Hotto	6,038,265 A	3/2000	Pan et al.
5,870,670 A	2/1999	Ripley et al.	6,041,073 A	3/2000	Davidovici et al.
5,872,446 A	2/1999	Cranford, Jr. et al.	6,044,332 A	3/2000	Korsah et al.
5,878,088 A	3/1999	Knutson et al.	6,047,026 A	4/2000	Chao et al.
5,881,375 A	3/1999	Bonds	6,049,573 A	4/2000	Song
5,883,548 A	3/1999	Assard et al.	6,049,706 A	4/2000	Cook et al.
5,884,154 A	3/1999	Sano et al.	6,054,889 A	4/2000	Kobayashi
5,886,547 A	3/1999	Durec et al.	6,057,714 A	5/2000	Andrys et al.
5,887,001 A	3/1999	Russell	6,061,551 A	5/2000	Sorrells et al.
5,892,380 A	4/1999	Quist	6,061,555 A	5/2000	Bultman et al.
5,894,239 A	4/1999	Bonaccio et al.	6,064,054 A	5/2000	Waczynski et al.
5,894,496 A	4/1999	Jones	6,067,329 A	5/2000	Kato et al.
5,896,304 A	4/1999	Tiemann et al.	6,072,996 A	6/2000	Smith
5,896,347 A	4/1999	Tomita et al.	6,073,001 A	6/2000	Sokoler
5,896,562 A	4/1999	Heinonen	6,076,015 A	6/2000	Hartley et al.
5,898,912 A	4/1999	Heck et al.	6,078,630 A	6/2000	Prasanna
5,900,746 A	5/1999	Sheahan	6,081,691 A	6/2000	Renard et al.
5,900,747 A	5/1999	Brauns	6,084,465 A	7/2000	Dasgupta
5,901,054 A	5/1999	Leu et al.	6,084,922 A	7/2000	Zhou et al.
5,901,187 A	5/1999	Iinuma	6,085,073 A	7/2000	Palermo et al.
5,901,344 A	5/1999	Opas	6,088,348 A	7/2000	Bell, III et al.
5,901,347 A	5/1999	Chambers et al.	6,091,289 A	7/2000	Song et al.
5,901,348 A	5/1999	Bang et al.	6,091,939 A	7/2000	Banh
5,901,349 A	5/1999	Guegnaud et al.	6,091,940 A	7/2000	Sorrells et al.
5,903,178 A	5/1999	Miyatsuji et al.	6,091,941 A	7/2000	Moriyama et al.
5,903,187 A	5/1999	Claverie et al.	6,094,084 A	7/2000	Abou-Allam et al.

## US 8,190,108 B2

Page 6

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6,097,762	A	8/2000	Suzuki et al.	6,546,061	B2	4/2003	Signell et al.
6,098,046	A	8/2000	Cooper et al.	6,560,301	B1	5/2003	Cook et al.
6,098,886	A	8/2000	Swift et al.	6,560,451	B1	5/2003	Somayajula
6,112,061	A	8/2000	Rapeli	6,567,483	B1	5/2003	Dent et al.
6,121,819	A	9/2000	Traylor	6,580,902	B1	6/2003	Sorrells et al.
6,125,271	A	9/2000	Rowland et al.	6,591,310	B1	7/2003	Johnson
6,128,746	A	10/2000	Clark et al.	6,597,240	B1	7/2003	Walburger et al.
6,137,321	A	10/2000	Bazarjani	6,600,795	B1	7/2003	Ohta et al.
6,144,236	A	11/2000	Vice et al.	6,600,911	B1	7/2003	Morishige et al.
6,144,331	A	11/2000	Jiang	6,608,647	B1	8/2003	King
6,144,846	A	11/2000	Durec	6,611,569	B1	8/2003	Schier et al.
6,147,340	A	11/2000	Levy	6,618,579	B1	9/2003	Smith et al.
6,147,763	A	11/2000	Steinlechner	6,625,470	B1	9/2003	Fourtet et al.
6,150,890	A	11/2000	Damgaard et al.	6,628,328	B1	9/2003	Yokouchi et al.
6,151,354	A	11/2000	Abbey	6,633,194	B2	10/2003	Arnborg et al.
6,160,280	A	12/2000	Bonn et al.	6,634,555	B1	10/2003	Sorrells et al.
6,167,247	A	12/2000	Kannell et al.	6,639,939	B1	10/2003	Naden et al.
6,169,733	B1	1/2001	Lee	6,647,250	B1	11/2003	Bultman et al.
6,175,728	B1	1/2001	Mitama	6,647,270	B1	11/2003	Himmelstein
6,178,319	B1	1/2001	Kashima	6,686,879	B2	2/2004	Shattil
6,182,011	B1	1/2001	Ward	6,687,493	B1	2/2004	Sorrells et al.
6,188,221	B1	2/2001	Van de Kop et al.	6,690,232	B2	2/2004	Ueno et al.
6,192,225	B1	2/2001	Arpaia et al.	6,690,741	B1	2/2004	Larrick, Jr. et al.
6,195,539	B1	2/2001	Galal et al.	6,694,128	B1	2/2004	Looke et al.
6,198,941	B1	3/2001	Aho et al.	6,697,603	B1	2/2004	Lovinggood et al.
6,204,789	B1	3/2001	Nagata	6,704,549	B1	3/2004	Sorrells et al.
6,208,636	B1	3/2001	Tawil et al.	6,704,558	B1	3/2004	Sorrells et al.
6,208,875	B1	3/2001	Damgaard et al.	6,731,146	B1	5/2004	Gallardo
RE37,138	E	4/2001	Dent	6,738,609	B1	5/2004	Clifford
6,211,718	B1	4/2001	Souetinov	6,738,611	B1	5/2004	Politi
6,212,369	B1	4/2001	Avasarala	6,741,139	B2	5/2004	Pleasant et al.
6,215,475	B1	4/2001	Meyerson et al.	6,741,650	B1	5/2004	Painchaud et al.
6,215,828	B1	4/2001	Signell et al.	6,775,684	B1	8/2004	Toyoyama et al.
6,215,830	B1	4/2001	Temerinac et al.	6,798,351	B1	9/2004	Sorrells et al.
6,223,061	B1	4/2001	Dacus et al.	6,801,253	B1	10/2004	Yonemoto et al.
6,225,848	B1	5/2001	Tilley et al.	6,813,320	B1	11/2004	Claxton et al.
6,230,000	B1	5/2001	Taylor	6,813,485	B2	11/2004	Sorrells et al.
6,246,695	B1	6/2001	Seazholtz et al.	6,823,178	B2	11/2004	Pleasant et al.
6,259,293	B1	7/2001	Hayase et al.	6,829,311	B1	12/2004	Riley
6,266,518	B1	7/2001	Sorrells et al.	6,836,650	B2	12/2004	Sorrells et al.
6,275,542	B1	8/2001	Katayama et al.	6,850,742	B2	2/2005	Fayyaz
6,298,065	B1	10/2001	Dombkowski et al.	6,853,690	B1	2/2005	Sorrells et al.
6,307,894	B2	10/2001	Eidson et al.	6,865,399	B2	3/2005	Fujioka et al.
6,308,058	B1	10/2001	Souetinov et al.	6,873,836	B1	3/2005	Sorrells et al.
6,313,685	B1	11/2001	Rabii	6,876,846	B2	4/2005	Tamaki et al.
6,313,700	B1	11/2001	Nishijima et al.	6,879,817	B1	4/2005	Sorrells et al.
6,314,279	B1	11/2001	Mohindra	6,882,194	B2	4/2005	Belot et al.
6,317,589	B1	11/2001	Nash	6,892,057	B2	5/2005	Nilsson
6,321,073	B1	11/2001	Luz et al.	6,892,062	B2	5/2005	Lee et al.
6,324,379	B1	11/2001	Hadden et al.	6,894,988	B1	5/2005	Zehavi
6,327,313	B1	12/2001	Traylor et al.	6,909,739	B1	6/2005	Eerola et al.
6,330,244	B1	12/2001	Swartz et al.	6,910,015	B2	6/2005	Kawai
6,332,007	B1	12/2001	Sasaki	6,917,796	B2	7/2005	Setty et al.
6,335,656	B1	1/2002	Goldfarb et al.	6,920,311	B2	7/2005	Rofougaran et al.
6,353,735	B1	3/2002	Sorrells et al.	6,959,178	B2	10/2005	Macedo et al.
6,363,126	B1	3/2002	Furukawa et al.	6,963,626	B1	11/2005	Shaeffer et al.
6,363,262	B1	3/2002	McNicol	6,963,734	B2	11/2005	Sorrells et al.
6,366,622	B1	4/2002	Brown et al.	6,973,476	B1	12/2005	Naden et al.
6,366,765	B1	4/2002	Hongo et al.	6,975,848	B2	12/2005	Rawlins et al.
6,370,371	B1	4/2002	Sorrells et al.	6,999,747	B2	2/2006	Su
6,385,439	B1	5/2002	Hellberg	7,006,805	B1	2/2006	Sorrells et al.
6,393,070	B1	5/2002	Reber	7,010,286	B2	3/2006	Sorrells et al.
6,400,963	B1	6/2002	Glöckler et al.	7,010,559	B2	3/2006	Rawlins et al.
6,404,758	B1	6/2002	Wang	7,016,663	B2	3/2006	Sorrells et al.
6,404,823	B1	6/2002	Grange et al.	7,027,786	B1	4/2006	Smith et al.
6,408,018	B1	6/2002	Dent	7,039,372	B1	5/2006	Sorrells et al.
6,421,534	B1	7/2002	Cook et al.	7,050,508	B2	5/2006	Sorrells et al.
6,437,639	B1	8/2002	Nguyen et al.	7,054,296	B1	5/2006	Sorrells et al.
6,438,366	B1	8/2002	Lindfors et al.	7,065,162	B1	6/2006	Sorrells et al.
6,441,694	B1	8/2002	Turcotte et al.	7,072,390	B1	7/2006	Sorrells et al.
6,445,726	B1	9/2002	Gharpurey	7,072,427	B2	7/2006	Rawlins et al.
6,459,721	B1	10/2002	Mochizuki et al.	7,076,011	B2	7/2006	Cook et al.
6,509,777	B2	1/2003	Razavi et al.	7,082,171	B1	7/2006	Johnson et al.
6,512,544	B1	1/2003	Merrill et al.	7,085,335	B2	8/2006	Rawlins et al.
6,512,785	B1	1/2003	Zhou et al.	7,107,028	B2	9/2006	Sorrells et al.
6,512,798	B1	1/2003	Akiyama et al.	7,110,435	B1	9/2006	Sorrells et al.
6,516,185	B1	2/2003	MacNally	7,110,444	B1	9/2006	Sorrells et al.
6,531,979	B1	3/2003	Hynes	7,149,487	B2	12/2006	Yoshizawa
6,542,722	B1	4/2003	Sorrells et al.	7,190,941	B2	3/2007	Sorrells et al.

## US 8,190,108 B2

Page 7

7,193,965	B1	3/2007	Nevo et al.	DE	196 27 640	A1	1/1997
7,194,044	B2	3/2007	Birkett et al.	DE	692 21 098	T2	1/1998
7,194,246	B2	3/2007	Sorrells et al.	DE	196 48 915	A1	6/1998
7,197,081	B2	3/2007	Saito	DE	197 35 798	C1	7/1998
7,209,725	B1	4/2007	Sorrells et al.	EM	0 643 477	A3	3/1995
7,212,581	B2	5/2007	Birkett et al.	EP	0 035 166	A1	9/1981
7,218,899	B2	5/2007	Sorrells et al.	EP	0 087 336	A1	8/1983
7,218,907	B2	5/2007	Sorrells et al.	EP	0 099 265	A1	1/1984
7,224,749	B2	5/2007	Sorrells et al.	EP	0 087 336	B1	7/1986
7,233,969	B2	6/2007	Rawlins et al.	EP	0 254 844	A2	2/1988
7,236,754	B2	6/2007	Sorrells et al.	EP	0 276 130	A2	7/1988
7,245,886	B2	7/2007	Sorrells et al.	EP	0 276 130	A3	7/1988
7,272,164	B2	9/2007	Sorrells et al.	EP	0 380 351	A2	8/1990
7,292,835	B2	11/2007	Sorrells et al.	EP	0 380 351	A3	2/1991
7,295,826	B1	11/2007	Cook et al.	EP	0 423 718	A2	4/1991
7,308,242	B2	12/2007	Sorrells et al.	EP	0 411 840	A3	7/1991
7,321,640	B2	1/2008	Milne et al.	EP	0 486 095	A1	5/1992
7,321,735	B1	1/2008	Smith et al.	EP	0 423 718	A3	8/1992
7,321,751	B2	1/2008	Sorrells et al.	EP	0 512 748	A2	11/1992
7,358,801	B2	4/2008	Perdoor et al.	EP	0 529 836	A1	3/1993
7,376,410	B2	5/2008	Sorrells et al.	EP	0 548 542	A1	6/1993
7,379,515	B2	5/2008	Johnson et al.	EP	0 512 748	A3	7/1993
7,379,883	B2	5/2008	Sorrells	EP	0 560 228	A1	9/1993
7,386,292	B2	6/2008	Sorrells et al.	EP	0 632 288	A2	1/1995
7,389,100	B2	6/2008	Sorrells et al.	EP	0 632 577	A1	1/1995
7,433,910	B2	10/2008	Rawlins et al.	EP	0 643 477	A2	3/1995
7,454,453	B2	11/2008	Rawlins et al.	EP	0 411 840	B1	10/1995
7,460,584	B2	12/2008	Parker et al.	EP	0 696 854	A1	2/1996
7,483,686	B2	1/2009	Sorrells et al.	EP	0 632 288	A3	7/1996
7,496,342	B2	2/2009	Sorrells et al.	EP	0 732 803	A1	9/1996
7,515,896	B1	4/2009	Sorrells et al.	EP	0 486 095	B1	2/1997
7,529,522	B2	5/2009	Sorrells et al.	EP	0 782 275	A2	7/1997
7,539,474	B2	5/2009	Sorrells et al.	EP	0 785 635	A1	7/1997
7,546,096	B2	6/2009	Sorrells et al.	EP	0 789 449	A2	8/1997
7,554,508	B2	6/2009	Johnson et al.	EP	0 789 449	A3	8/1997
7,599,421	B2	10/2009	Sorrells et al.	EP	0 795 955	A2	9/1997
7,620,378	B2	11/2009	Sorrells et al.	EP	0 795 955	A3	9/1997
7,653,145	B2	1/2010	Sorrells et al.	EP	0 795 978	A2	9/1997
7,653,158	B2	1/2010	Rawlins et al.	EP	0 817 369	A2	1/1998
7,693,230	B2	4/2010	Sorrells et al.	EP	0 817 369	A3	1/1998
7,693,502	B2	4/2010	Sorrells et al.	EP	0 837 565	A1	4/1998
7,697,916	B2	4/2010	Sorrells et al.	EP	0 862 274	A1	9/1998
7,724,845	B2	5/2010	Sorrells et al.	EP	0 874 499	A2	10/1998
7,773,688	B2	8/2010	Sorrells et al.	EP	0 512 748	B1	11/1998
7,783,250	B2	8/2010	Lynch	EP	0 877 476	A1	11/1998
7,822,401	B2	10/2010	Sorrells et al.	EP	0 411 840	A2	2/1999
7,826,817	B2	11/2010	Sorrells et al.	EP	0 977 351	A1	2/2000
7,865,177	B2	1/2011	Sorrells et al.	ER	0 193 899	B1	6/1990
7,894,789	B2	2/2011	Sorrells et al.	FR	2 245 130		4/1975
7,929,638	B2	4/2011	Sorrells et al.	FR	2 669 787	A1	5/1992
7,936,022	B2	5/2011	Sorrells et al.	FR	2 743 231	A1	7/1997
7,937,059	B2	5/2011	Sorrells et al.	GB	2 161 344	A	1/1986
7,991,815	B2	8/2011	Rawlins et al.	GB	2 215 945	A	9/1989
8,019,291	B2	9/2011	Sorrells et al.	GB	2 324 919	A	11/1998
8,036,304	B2	10/2011	Sorrells et al.	JO	61-232706		10/1986
8,077,797	B2	12/2011	Sorrells	JO	7-169292	A	7/1995
2001/0015673	A1	8/2001	Yamashita et al.	JP	47-2314		2/1972
2001/0036818	A1	11/2001	Dobrovolny	JP	55-66057		5/1980
2002/0021685	A1	2/2002	Sakusabe	JP	56-114451		9/1981
2002/0037706	A1	3/2002	Ichihara	JP	58-7903		1/1983
2002/0080728	A1	6/2002	Sugar et al.	JP	58-031622		2/1983
2002/0098823	A1	7/2002	Lindfors et al.	JP	58-133004		8/1983
2002/0132642	A1	9/2002	Hines et al.	JP	59-022438		2/1984
2002/0163921	A1	11/2002	Ethridge et al.	JP	59-123318		7/1984
2003/0045263	A1	3/2003	Wakayama et al.	JP	59-144249		8/1984
2003/0078011	A1	4/2003	Cheng et al.	JP	60-58705		4/1985
2003/0081781	A1	5/2003	Jensen et al.	JP	60-130203		7/1985
2003/0149579	A1	8/2003	Begemann et al.	JP	61-30821		2/1986
2003/0193364	A1	10/2003	Liu et al.	JP	61-193521		8/1986
2004/0125879	A1	7/2004	Jaussi et al.	JP	61-245749		11/1986
2006/0002491	A1	1/2006	Darabi et al.	JP	62-12381		1/1987
2006/0039449	A1	2/2006	Fontana et al.	JP	62-047214		2/1987
2006/0209599	A1	9/2006	Kato et al.	JP	63-54002		3/1988
2009/0318097	A1*	12/2009	Sorrells et al. .... 455/118	JP	63-65587		3/1988
2010/0056084	A1	3/2010	Sorrells et al.	JP	63-153691		6/1988
FOREIGN PATENT DOCUMENTS				JP	63-274214		11/1988
DE	35 41 031	A1	5/1986	JP	64-048557		2/1989
DE	42 37 692	C1	3/1994	JP	2-39632		2/1990
				JP	2-131629		5/1990

## US 8,190,108 B2

Page 8

JP	2-276351	11/1990
JP	4-123614	4/1992
JP	4-127601	4/1992
JP	4-154227	5/1992
JP	5-175730	7/1993
JP	5-175734	7/1993
JP	5-327356	12/1993
JP	6-237276	8/1994
JP	6-284038	10/1994
JP	7-154344	6/1995
JP	7-307620	11/1995
JP	8-23359	1/1996
JP	8-32556	2/1996
JP	8-139524	5/1996
JP	8-288882 A	11/1996
JP	9-36664	2/1997
JP	9-171399	6/1997
JP	10-22804 A	1/1998
JP	10-41860	2/1998
JP	10-96778	4/1998
JP	10-173563	6/1998
JP	11-98205	4/1999
WO	WO 80/01633 A1	8/1980
WO	WO 91/18445 A1	11/1991
WO	WO 94/05087 A1	3/1994
WO	WO 95/01006 A1	1/1995
WO	WO 95/19073 A2	7/1995
WO	WO 96/02977 A1	2/1996
WO	WO 96/08078 A1	3/1996
WO	WO 96/39750 A1	12/1996
WO	WO 97/08839 A2	3/1997
WO	WO 97/08839 A3	3/1997
WO	WO 97/38490 A1	10/1997
WO	WO 98/00953 A1	1/1998
WO	WO 98/24201 A1	6/1998
WO	WO 98/40968 A2	9/1998
WO	WO 98/40968 A3	9/1998
WO	WO 98/53556 A2	11/1998
WO	WO 99/23755 A1	5/1999
WO	WO 00/31659 A1	6/2000

## OTHER PUBLICATIONS

Akers, N. P. et al., "RF Sampling Gates: a Brief Review," *IEE Proceedings*, IEE, vol. 133, Part A, No. 1, pp. 45-49 (Jan. 1986).

Al-Ahmad, H.A.M. et al., "Doppler Frequency Correction for a Non-Geostationary Communications Satellite. Techniques for CERS and T-SAT," *Electronics Division Colloquium on Low Noise Oscillators and Synthesizers*, IEE, pp. 4/1-4/5 (Jan. 23, 1986).

Ali, I. et al., "Doppler Characterization for LEO Satellites," *IEEE Transactions on Communications*, IEEE, Vol. 46, No. 3, pp. 309-313 (Mar. 1998).

Allan, D.W., "Statistics of Atomic Frequency Standards," *Proceedings of the IEEE Special issue on Frequency Stability*, IEEE, pp. 221-230 (Feb. 1966).

Allstot, D.J. et al., "MOS Switched Capacitor Ladder Filters," *IEEE Journal of Solid-State Circuits*, IEEE, vol. SC-13, No. 6, pp. 806-814 (Dec. 1978).

Allstot, D.J. And Black Jr. W.C., "Technological Design Considerations for Monolithic MOS Switched-Capacitor Filtering Systems," *Proceedings of the IEEE*, IEEE, vol. 71, No. 8, pp. 967-986 (Aug. 1983).

Alouini, M. et al., "Channel Characterization and Modeling for Ka-Band Very Small Aperture Terminals," *Proceedings of the IEEE*, IEEE, vol. 85, No. 6, pp. 981-997 (Jun. 1997).

Andreyev, G.A. and Ogarev, S.A., "Phase Distortions of Keyed Millimeter-Wave Signals in the Case of Propagation in a Turbulent Atmosphere," *Telecommunications and Radio Engineering*, Scripta Technica, vol. 43, No. 12, pp. 87-90 (Dec. 1988).

Antonetti, A. et al., "Optoelectronic Sampling in the Picosecond Range," *Optics Communications*, North-Holland Publishing Company, vol. 21, No. 2, pp. 211-214 (May 1977).

Austin, J. et al., "Doppler Correction of the Telecommunication Payload Oscillators in the UK T-SAT," *18<sup>th</sup> European Microwave Conference*, Microwave Exhibitions and Publishers Ltd., pp. 851-857 (Sep. 12-15, 1988).

Auston, D.H., "Picosecond optoelectronic switching and gating in silicon," *Applied Physics Letters*, American Institute of Physics, vol. 26, No. 3, pp. 101-103 (Feb. 1, 1975).

Baher, H., "Transfer Functions for Switched-Capacitor and Wave Digital Filters," *IEEE Transactions on Circuits and Systems*, IEEE Circuits and Systems Society, vol. CAS-33, No. 11, pp. 1138-1142 (Nov. 1986).

Baines, R., "The DSP Bottleneck," *IEEE Communications Magazine*, IEEE Communications Society, pp. 46-54 (May 1995).

Banjo, O.P. and Vilar, E., "Binary Error Probabilities on Earth-Space Links Subject to Scintillation Fading," *Electronics Letters*, IEE, vol. 21, No. 1, pp. 296-297 (Mar. 28, 1985).

Banjo, O.P. and Vilar, E., "The Dependence of Slant Path Amplitude Scintillations on Various Meteorological Parameters," *Fifth International Conference on Antennas and Propagation (ICAP 87) Part 2: Propagation*, IEE, pp. 277-280 (Mar. 30-Apr. 2, 1987).

Banjo, O.P. and Vilar, E., "Measurement and Modeling of Amplitude Scintillations on Low-Elevation Earth-Space Paths and Impact on Communication Systems," *IEEE Transactions on Communications*, IEEE Communications Society, vol. COM-34, No. 8, pp. 774-780 (Aug. 1986).

Banjo, O.P. et al., "Tropospheric Amplitude Spectra Due to Absorption and Scattering in Earth-Space Paths," *Fourth International Conference on Antennas and Propagation (ICAP 85)*, IEE, pp. 77-82 (Apr. 16-19, 1985).

Basili, P. et al., "Case Study of Intense Scintillation Events on the OTS Path," *IEEE Transactions on Antennas and Propagation*, IEEE, vol. 38, No. 1, pp. 107-113 (Jan. 1990).

Basili, P. et al., "Observation of High C<sup>2</sup> and Turbulent Path Length on OTS Space-Earth Link," *Electronics Letters*, IEE, vol. 24, No. 17, pp. 1114-1116 (Aug. 18, 1988).

Blakey, J.R. et al., "Measurement of Atmospheric Millimetre-Wave Phase Scintillations in an Absorption Region," *Electronics Letters*, IEE, vol. 21, No. 11, pp. 486-487 (May 23, 1985).

Burgueño, et al., "Influence of rain gauge integration time on the rain rate statistics used in microwave communications," *Annales des télécommunications*, International Union of Radio Science, pp. 522-527 (Sep./Oct. 1988).

Burgueño, A. et al., "Long-Term Joint Statistical Analysis of Duration and Intensity of Rainfall Rate with Application to Microwave Communications," *Fifth International Conference on Antennas and Propagation (ICAP 87) Part 2: Propagation*, IEE, pp. 198-201 (Mar. 30-Apr. 2, 1987).

Burgueño, A. et al., "Long Term Statistics of Precipitation Rate Return Periods in the Context of Microwave Communications," *Sixth International Conference on Antennas and Propagation (ICAP 89) Part 2: Propagation*, IEE, pp. 297-301 (Apr. 4-7, 1989).

Burgueño, A. et al., "Spectral Analysis of 49 Years of Rainfall Rate and Relation to Fade Dynamics," *IEEE Transactions on Communications*, IEEE Communications Society, vol. 38, No. 9, pp. 1359-1366 (Sep. 1990).

Catalan, C. And Vilar, E., "Approach for satellite slant path remote sensing," *Electronics Letters*, IEE, vol. 34, No. 12, pp. 1238-1240 (Jun. 11, 1998).

Chan, P. et al., "A Highly Linear 1-GHz CMOS Downconversion Mixer," *European Solid State Circuits Conference*, IEEE Communication Society, pp. 210-213 (Sep. 22-24, 1993).

Declaration of Michael J. Bultman filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 2 pages.

Declaration of Robert W. Cook filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 2 pages.

Declaration of Alex Holtz filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 3 pages.

Declaration of Richard C. Looke filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 2 pages.

Declaration of Charley D. Moses, Jr. filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 2 pages.

Declaration of Jeffrey L. Parker and David F. Sorrells, with attachment Exhibit I, filed in U.S. Appl. No. 09/176,022, which is directed to related subject matter, 130 pages.

Dewey, R.J. and Collier, C.J., "Multi-Mode Radio Receiver," *Electronics Division Colloquium on Digitally Implemented Radios*, IEE, pp. 3/1-3/5 (Oct. 18, 1985).

## US 8,190,108 B2

Page 9

- Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2-276351, 1 page (Nov. 13, 1990—Date of publication of application).
- Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2-131629, 1 page (May 21, 1990—Date of publication of application).
- Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2-39632, 1 page (Feb. 8, 1990—Date of publication of application).
- Dialog File 348 (European Patents) English Language Patent Abstract for EP 0 785 635 A1, 3 pages (Dec. 26, 1996—Date of publication of application).
- Dialog File 348 (European Patents) English Language Patent Abstract for EP 35166 A1, 2 pages (Feb. 18, 1981—Date of publication of application).
- "DSO takes sampling rate to 1 Ghz," *Electronic Engineering*, Morgan Grampian Publishers, vol. 59, No. 723, pp. 77 and 79 (Mar. 1987).
- Erdi, G. and Henneuse, P.R., "A Precision FET-Less Sample-and-Hold with High Charge-to-Droop Current Ratio," *IEEE Journal of Solid-State Circuits*, IEEE vol. SC-13, No. 6, pp. 864-873 (Dec. 1978).
- Faulkner, N.D. and Vilar, E., "Subharmonic Sampling for the Measurement of Short Term Stability of Microwave Oscillators," *IEEE Transactions on Instrumentation and Measurement*, IEEE, vol. IM-32, No. 1, pp. 208-213 (Mar. 1983).
- Faulkner, N.D. et al., "Sub-Harmonic Sampling for the Accurate Measurement of Frequency Stability of Microwave Oscillators," *CPEM 82 Digest: Conference on Precision Electromagnetic Measurements*, IEEE, pp. M-10 and M-11 (1982).
- Faulkner, N.D. and Vilar, E., "Time Domain Analysis of Frequency Stability Using Non-Zero Dead-Time Counter Techniques," *CPEM 84 Digest Conference on Precision Electromagnetic Measurements*, IEEE, pp. 81-82 (1984).
- Filip, M. and Viler, E., "Optimum Utilization of the Channel Capacity of a Satellite Link in the Presence of Amplitude Scintillations and Rain Attenuation," *IEEE Transactions on Communications*, IEEE Communications Society, vol. 38, No. 11, pp. 1958-1965 (Nov. 1990).
- Fukahori, K., "A CMOS Narrow-Band Signaling Filter with Q Reduction," *IEEE Journal of Solid-State Circuits*, IEEE, vol. SC-19, No. 6, pp. 926-932 (Dec. 1984).
- Fukuchi, H. and Otsu, Y., "Available time statistics of rain attenuation on earth-space path," *IEE Proceedings—H: Microwaves, Antennas and Propagation*, IEE, vol. 135, Pt. H, No. 6, pp. 387-390 (Dec. 1988).
- Gibbins, C.J. and Chadha, R., "Millimetre-wave propagation through hydrocarbon flame," *IEE Proceedings*, IEE, vol. 134, Pt. H, No. 2, pp. 169-173 (Apr. 1987).
- Gilchrist, B. et al., "Sampling hikes performance of frequency synthesizers," *Microwaves & RF*, Hayden Publishing, vol. 23, No. 1, pp. 93-94 and 110 (Jan. 1984).
- Gossard, E.E., "Clear weather meteorological effects on propagation at frequencies above 1 Ghz," *Radio Science*, American Geophysical Union, vol. 16, No. 5, pp. 589-608 (Sep.-Oct. 1981).
- Gregorian, R. et al., "Switched-Capacitor Circuit Design," *Proceedings of the IEEE*, IEEE vol. 71, No. 8, pp. 941-966 (Aug. 1983).
- Groshong et al., "Undersampling Techniques Simplify Digital Radio," *Electronic Design*, Penton Publishing, pp. 67-68, 70, 73-75 and 78 (May 23, 1991).
- Grove, W.M., "Sampling for Oscilloscopes and Other RF Systems: Dc through X-Band," *IEEE Transactions on Microwave Theory and Techniques*, IEEE, pp. 629-635 (Dec. 1966).
- Haddon, J. et al., "Measurement of Microwave Scintillations on a Satellite Down-Link at X-Band," *Antennas and Propagation*, IEE, pp. 113-117 (1981).
- Haddon, J. and Vilar, E., "Scottering Induced Microwave Scintillations from Clear Air and Rain on Earth Space Paths and the Influence of Antenna Aperture," *IEEE Transactions on Antennas and Propagation*, IEEE, vol. AP-34, No. 5, pp. 646-657 (May 1986).
- Hafidallah, H. et al., "2-4 Ghz MESFET Sampler," *Electronics Letters*, IEE, vol. 24, No. 3, pp. 151-153 (Feb. 4, 1988).
- Herben, M.H.A.J., "Amplitude and Phase Scintillation Measurements on 8-2 km Line-Of-Sight Path at 30 Ghz," *Electronics Letters*, IEE, vol. 18, No. 7, pp. 287-289 (Apr. 1, 1982).
- Hewitt, A. et al., "An 18 Ghz Wideband LOS Multipath Experiment," *International Conference on Measurements for Telecommunication Transmission Systems—MTTS 85*, IEE, pp. 112-116 (Nov. 27-28, 1985).
- Hewitt, A. et al., "An Autoregressive Approach to the Identification of Multipath Ray Parameters from Field Measurements," *IEEE Transactions on Communications*, IEEE Communications Society, vol. 37, No. 11, pp. 1136-1143 (Nov. 1989).
- Hewitt, A. and Viler, E., "Selective fading on LOS Microwave Links: Classical and Spread-Spectrum Measurement Techniques," *IEEE Transactions on Communications*, IEEE Communications Society, vol. 36, No. 7, pp. 789-796 (Jul. 1988).
- Hospitalier, E., "Instruments for Recording and Observing Rapidly Varying Phenomena," *Science Abstracts*, IEE, vol. VII, pp. 22-23 (1904).
- Howard, I.M. and Swansson, N.S., "Demodulating High Frequency Resonance Signals for Bearing Fault Detection," *The Institution of Engineers Australia Vibration and Noise Conference*, Institution of Engineers, Australia, pp. 115-121 (Sep. 18-20, 1990).
- Hu, X., *A Switched-Current Sample-and-Hold Amplifier for FM Demodulation*, Thesis for Master of Applied Science, Dept. of Electrical and Computer Engineering, University of Toronto, UMI Dissertation Services, pp. 1-64 (1995).
- Hung H-L. A. et al., "Characterization of Microwave Integrated Circuits Using an Optical Phase-Locking and Sampling System," *IEEE MTT-S Digest*, IEEE, pp. 507-510 (1991).
- Hurst, P.J., "Shifting the Frequency Response of Switched-Capacitor Filters by Nonuniform Sampling," *IEEE Transactions on Circuits and Systems*, IEEE Circuits and Systems Society, vol. 38, No. 1, pp. 12-19 (Jan. 1991).
- Itakura, T., "Effects of the sampling pulse width on the frequency characteristics of a sample-and-hold circuit," *IEE Proceedings Circuits, Devices and Systems*, IEE, vol. 141, No. 4, pp. 328-336 (Aug. 1994).
- Janseen, J.M.L., "An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: I. Fundamentals," *Philips Technical Review*, Philips Research Laboratories, vol. 12, No. 2, pp. 52-59 (Aug. 1950).
- Janseen, J.M.L. and Michels, A.J., "An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: II. Electrical Build-Up," *Philips Technical Review*, Philips Research Laboratories, vol. 12, No. 3, pp. 73-82 (Sep. 1950).
- Jondral, V.F. et al., "Doppler Profiles for Communication Satellites," *Frequenz*, Herausberger, pp. 111-116 (May-Jun. 1996).
- Kaleh, G.K., "A Frequency Diversity Spread Spectrum System for Communication in the Presence of In-band Interference," *1995 IEEE Globecom*, IEEE Communications Society, pp. 66-70 (1995).
- Karasawa, Y. et al., "A New Prediction Method for Tropospheric Scintillation on Earth-Space Paths," *IEEE Transactions on Antennas and Propagation*, IEEE Antennas and Propagation Society, vol. 36, No. 11, pp. 1608-1614 (Nov. 1988).
- Kirsten, J. and Fleming, J., "Undersampling reduces data-acquisition costs for select applications," *EDN*, Cahners Publishing, vol. 35, No. 13, pp. 217-222, 224, 226-228 (Jun. 21, 1990).
- Lam, W.K. et al., "Measurement of the Phase Noise Characteristics of an Unlocked Communications Channel Identifier," *Proceedings of the 1993 IEEE International Frequency Control Symposium*, IEEE, pp. 283-288 (Jun. 2-4, 1993).
- Lam, W.K. et al., "Wideband sounding of 11.6 Ghz transhorizon channel," *Electronics Letters*, IEE, vol. 30, No. 9, pp. 738-739 (Apr. 28, 1994).
- Larkin, K.G., "Efficient demodulator for bandpass sampled AM signals," *Electronics Letters*, IEE, vol. 32, No. 2, pp. 101-102 (Jan. 18, 1996).
- Lau, W.H. et al., "Analysis of the Time Variant Structure of Microwave Line-of-sight Multipath Phenomena," *IEEE Global Telecommunications Conference & Exhibition*, IEEE, pp. 1707-1711 (Nov. 28-Dec. 1, 1988).
- Lau, W.H. et al., "Improved Prony Algorithm to Identify Multipath Components," *Electronics Letters*, IEE, vol. 23, No. 20, pp. 1059-1060 (Sep. 24, 1987).
- Lesage, P. and Audoin, C., "Effect of Dead-Time on the Estimation of the Two-Sample Variance," *IEEE Transactions on Instrumentation*

## US 8,190,108 B2

Page 10

- and Measurement, IEEE Instrumentation and Measurement Society, vol. IM-28, No. 1, pp. 6-10 (Mar. 1979).
- Liechti, C.A., "Performance of Dual-gate GaAs MESFET's as Gain-Controlled Low-Noise Amplifiers and High-Speed Modulators," *IEEE Transactions on Microwave Theory and Techniques*, IEEE Microwave Theory and Techniques Society, vol. MTT-23, No. 6, pp. 461-469 (Jun. 1975).
- Linnenbrink, T.E. et al., "A One Gigasample Per Second Transient Recorder," *IEEE Transactions on Nuclear Science*, IEEE Nuclear and Plasma Sciences Society, vol. NS-26, No. 4, pp. 4443-4449 (Aug. 1979).
- Liou, M.L., "A Tutorial on Computer-Aided Analysis of Switched-Capacitor Circuits," *Proceedings of the IEEE*, IEEE, vol. 71, No. 8, pp. 987-1005 (Aug. 1983).
- Lo, P. et al., "Coherent Automatic Gain Control," *IEE Colloquium on Phase Locked Techniques*, IEE, pp. 2/1-2/6 (Mar. 26, 1980).
- Lo, P. et al., "Computation of Rain Induced Scintillations on Satellite Down-Links at Microwave Frequencies," *Third International Conference on Antennas and Propagation (ICAP 83)*, pp. 127-131 (Apr. 12-15, 1983).
- Lo, P.S.L.O. et al., "Observations of Amplitude Scintillations on a Low-Elevation Earth-Space Path," *Electronics Letters*, IEE, vol. 20, No. 7, pp. 307-308 (Mar. 29, 1984).
- Madahi, K. And Aithison, C.S., "A 20 Ghz Microwave Sampler," *IEEE Transactions on Microwave Theory and Techniques*, IEEE Microwave Theory and Techniques Society, Vol. 40, No. 10, pp. 1960-1963 (Oct. 1992).
- Marsland, R.A. et al., "130 Ghz GaAs monolithic integrated circuit sampling head," *Appl. Phys. Lett.*, American Institute of Physics, vol. 55, No. 6, pp. 592-594 (Aug. 7, 1989).
- Martin, K. and Sedra, A.S., "Switched-Capacitor Building Blocks for Adaptive Systems," *IEEE Transactions on Circuits and Systems*, IEEE Circuits and Systems Society, vol. CAS-28, No. 6, pp. 576-584 (Jun. 1981).
- Marzano, F.S. and d'Auria, G., "Model-based Prediction of Amplitude Scintillation variance due to Clear-Air Tropospheric Turbulence on Earth-Satellite Microwave Links," *IEEE Transactions on Antennas and Propagation*, IEEE Antennas and Propagation Society, vol. 46, No. 10, pp. 1506-1518 (Oct. 1998).
- Matricciani, E., "Prediction of fade durations due to rain in satellite communication systems," *Radio Science*, American Geophysical Union, vol. 32, No. 3, pp. 935-941 (May-Jun. 1997).
- McQueen, J.G., "The Monitoring of High-Speed Waveforms," *Electronic Engineering*, Morgan Brothers Limited vol. XXIV, No. 296, pp. 436-441 (Oct. 1952).
- Merkelo, J. and Hall, R.D., "Broad-Band Thin-Film Signal Sampler," *IEEE Journal of Solid-State Circuits*, IEEE vol. SC-7, No. 1, pp. 50-54 (Feb. 1972).
- Merlo, U. et al., "Amplitude Scintillation Cycles in a Sirio Satellite-Earth Link," *Electronics Letters*, IEE, vol. 21, No. 23, pp. 1094-1096 (Nov. 7, 1985).
- Morris, D., "Radio-holographic reflector measurement of the 30-m millimeter radio telescope at 22 Ghz with a cosmic signal source," *Astronomy and Astrophysics*, Springer-Verlag, vol. 203, No. 2, pp. 399-406 (Sep. 2, 1988).
- Moulsley, T.J. et al., "The efficient acquisition and processing of propagation statistics," *Journal of the Institution of Electronic and Radio Engineers*, IERE, vol. 55, No. 3, pp. 97-103 (Mar. 1985).
- Ndizi, D. et al., "Wide-Band Statistical Characterization of n Over-the-Sea Experimental Transhorizon Link," *IEE Colloquium on Radio Communications and Microwave and Millimetre Wave Frequencies*, IEEE pp. 1/1-1/6 (Dec. 16, 1996).
- Ndizi, D. et al., "Wideband Statistics of Signal Levels and Doppler Spread on an Over-The-Sea Transhorizon Link," *IEE Colloquium on Propagation Characteristics and Related System Techniques for Beyond Line-of-Sight Radio*, IEE, pp. 9/1-9/6. (Nov. 24, 1997).
- "New zero IF chipset from Philips," *Electronic Engineering*, United News & Media, vol. 67, No. 825, p. 10 (Sep. 1995).
- Ohara, H. et al., "First monolithic PCM filter cuts cost of telecomm systems," *Electronic Design*, Hayden Publishing Company, vol. 27, No. 8, pp. 130-135 (Apr. 12, 1979).
- Oppenheim, A.V. et al., *Signals and Systems*, Prentice-Hall, pp. 527-531 and 561-562 (1983).
- Ortgies, G., "Experimental Parameters Affecting Amplitude Scintillation Measurements on Satellite Links," *Electronics Letters*, IEE, vol. 21, No. 17, pp. 771-772 (Aug. 15, 1985).
- Pärssinen et al., "A 2-GHz Subharmonic Sampler for Signal Downconversion," *IEEE Transactions on Microwave Theory and Techniques*, IEEE, vol. 45, No. 12, 7 pages (Dec. 1997).
- Peeters, G. et al., "Evaluation of Statistical Models for Clear-Air Scintillation Prediction Using Olympus Satellite Measurements," *International Journal of Satellite Communications*, John Wiley and Sons, vol. -15, No. 2, pp. 73-88 (Mar.-Apr. 1997).
- Perry, A.G. and Schoenwetter, H.K., *NBS Technical Note 1121: A Schottky Diode Bridge Sampling Gate*, U.S. Dept. of Commerce, pp. 1-14 (May 1980).
- Poulton, K. et al., "A 1-Ghz 6-bit ADC System," *IEEE Journal of Solid-State Circuits*, IEEE, vol. SC-22, No. 6, pp. 962-969 (Dec. 1987).
- Press Release, "Parkervision, Inc. Announces Fiscal 1993 Results," Lippert/Heilshorn and Associates, 2 Pages (Apr. 6, 1994).
- Press Release, "Parkervision, Inc. Announces the Appointment of Michael Baker to the New Position of National Sales Manager," Lippert/Heilshorn and Associates, 1 Page (Apr. 7, 1994).
- Press Release, "Parkervision's Cameraman Well-Received by Distance Learning Market," Lippert/Heilshorn and Associates, 2 Pages (Apr. 8, 1994).
- Press Release, "Parkervision, Inc. Announces First Quarter Financial Results," Lippert/Heilshorn and Associates, 2 Pages (Apr. 26, 1994).
- Press Release, "Parkervision, Inc. Announces The Retirement of William H. Fletcher, Chief Financial Officer," Lippert/Heilshorn and Associates, 1 Page (May 11, 1994).
- Press Release, "Parkervision, Inc. Announces New Cameraman System II™ at Infocomm Trade Show," Lippert/Heilshorn and Associates, 3 Pages (Jun. 9, 1994).
- Press Release, "Parkervision, Inc. Announces Appointments to its National Sales Force," Lippert/Heilshorn and Associates, 2 Pages (Jun. 17, 1994).
- Press Release, "Parkervision, Inc. Announces Second Quarter and Six Months Financial Results," Lippert/Heilshorn and Associates, 3 Pages (Aug. 9, 1994).
- Press Release, "Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results," Lippert/Heilshorn and Associates, 3 Pages (Oct. 28, 1994).
- Press Release, "Parkervision, Inc. Announces First Significant Dealer Sale of Its Cameraman® System II," Lippert/Heilshorn and Associates, 2 Pages (Nov. 7, 1994).
- Press Release, "Parkervision, Inc. Announces Fourth Quarter and Year End Results," Lippert/Heilshorn and Associates, 2 Pages (Mar. 1, 1995).
- Press Release, "Parkervision, Inc. Announces Joint Product Developments With VTEL," Lippert/Heilshorn and Associates, 2 Pages (Mar. 21, 1995).
- Press Release, "Parkervision, Inc. Announces First Quarter Financial Results," Lippert/Heilshorn and Associates, 3 Pages (Apr. 28, 1995).
- Press Release, "Parkervision Wins Top 100 Product Districts' Choice Award," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Jun. 29, 1995).
- Press Release, "Parkervision National Sales Manager Next President of USDLA," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Jul. 6, 1995).
- Press Release, "Parkervision Granted New Patent," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Jul. 21, 1995).
- Press Release, "Parkervision, Inc. Announces Second Quarter and Six Months Financial Results," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jul. 31, 1995).
- Press Release, "Parkervision, Inc. Expands Its Cameraman System II Product Line," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Sep. 22, 1995).
- Press Release, "Parkervision Announces New Camera Control Technology," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 25, 1995).
- Press Release, "Parkervision, Inc. Announces Completion of VTEL/Parkervision Joint Product Line," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 30, 1995).

## US 8,190,108 B2

Page 11

- Press Release, "Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 30, 1995).
- Press Release, "Parkervision's Cameraman Personal Locator Camera System Wins Telecon XV Award," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Nov. 1, 1995).
- Press Release, "Parkervision, Inc. Announces Purchase Commitment From VTEL Corporation," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Feb. 26, 1996).
- Press Release, "Parkervision, Inc. Announces Fourth Quarter and Year End Results," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Feb. 27, 1996).
- Press Release, "Parkervision, Inc. Expands its Product Line," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Mar. 7, 1996).
- Press Release, "Parkervision Files Patents for its Research of Wireless Technology," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Mar. 28, 1996).
- Press Release, "Parkervision, Inc. Announces First Significant Sale of its Cameraman® Three-Chip System," Parkervision Marketing and Manufacturing Headquarters, 2 pages (Apr. 12, 1996).
- Press Release, "Parkervision, Inc. Introduces New Product Line for Studio Production Market," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Apr. 15, 1996).
- Press Release, "Parkervision, Inc. Announces Private Placement of 800,000 Shares," Parkervision Marketing and Manufacturing Headquarters, 1 Page (Apr. 15, 1996).
- Press Release, "Parkervision, Inc. Announces First Quarter Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Apr. 30, 1996).
- Press Release, "Parkervision's New Studio Product Wins Award," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jun. 5, 1996).
- Press Release, "Parkervision, Inc. Announces Second Quarter and Six Months Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Aug. 1, 1996).
- Press Release, "Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 29, 1996).
- Press Release, "PictureTel and Parkervision Sign Reseller Agreement," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 30, 1996).
- Press Release, "CLI and Parkervision Bring Enhanced Ease-of-Use to Videoconferencing," CLI/Parkervision, 2 Pages (Jan. 20, 1997).
- Press Release, "Parkervision, Inc. Announces Fourth Quarter and Year End Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Feb. 27, 1997).
- Press Release, "Parkervision, Inc. Announces First Quarter Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Apr. 29, 1997).
- Press Release, "NEC and Parkervision Make Distance Learning Closer," NEC America, 2 Pages (Jun. 18, 1997).
- Press Release, "Parkervision Supplies JPL with Robotic Cameras, Cameraman Shot Director for Mars Mission," Parkervision Marketing and Manufacturing Headquarters, 2 pages (Jul. 8, 1997).
- Press Release, "Parkervision and IBM Join Forces to Create Wireless Computer Peripherals," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jul. 23, 1997).
- Press Release, "Parkervision, Inc. Announces Second Quarter and Six Months Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Jul. 31, 1997).
- Press Release, "Parkervision, Inc. Announces Private Placement of 990,000 Shares," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Sep. 8, 1997).
- Press Release, "Wal-Mart Chooses Parkervision for Broadcast Production," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Oct. 24, 1997).
- Press Release, "Parkervision, Inc. Announces Third Quarter Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Oct. 30, 1997).
- Press Release, "Parkervision Announces Breakthrough in Wireless Radio Frequency Technology," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Dec. 10, 1997).
- Press Release, "Parkervision, Inc. Announces the Appointment of Joseph F. Skovron to the Position of Vice President, Licensing—Wireless Technologies," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jan. 9, 1998).
- Press Release, "Parkervision Announces Existing Agreement with IBM Terminates—Company Continues with Strategic Focus Announced in December," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jan. 27, 1998).
- Press Release, "Laboratory Tests Verify Parkervision Wireless Technology," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Mar. 3, 1998).
- Press Release, "Parkervision, Inc. Announces Fourth Quarter and Year End Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Mar. 5, 1998).
- Press Release, "Parkervision Awarded Editors' Pick of Show for NAB 98," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Apr. 15, 1998).
- Press Release, "Parkervision Announces First Quarter Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (May 4, 1998).
- Press Release, "Parkervision 'DIRECT2DATA' Introduced in Response to Market Demand," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Jul. 9, 1998).
- Press Release, "Parkervision Expands Senior Management Team," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Jul. 29, 1998).
- Press Release, "Parkervision Announces Second Quarter and Six Month Financial Results," Parkervision Marketing and Manufacturing Headquarters, 4 Pages (Jul. 30, 1998).
- Press Release, "Parkervision Announces Third Quarter and Nine Month Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Oct. 30, 1998).
- Press Release, "Questar Infocomm, Inc. Invests \$5 Million in Parkervision Common Stock," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Dec. 2, 1998).
- Press Release, "Parkervision Adds Two New Directors," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Mar. 5, 1999).
- Press Release, "Parkervision Announces Fourth Quarter and Year End Financial Results," Parkervision Marketing and Manufacturing Headquarters, 3 Pages (Mar. 5, 1999).
- Press Release, "Joint Marketing Agreement Offers New Automated Production Solution," Parkervision Marketing and Manufacturing Headquarters, 2 Pages (Apr. 13, 1999).
- "Project COST 205: Scintillations in Earth-satellite links," *Alta Frequenza: Scientific Review in Electronics*, AEI, vol. LIV, No. 3, pp. 209-211 (May-Jun. 1985).
- Razavi, B., *RF Microelectronics*, Prentice-Hall, pp. 147-149 (1998).
- Reeves, R.J.D., "The Recording and Collocation of Waveforms (Part 1)," *Electronic Engineering*, Morgan Brothers Limited, vol. 31, No. 373, pp. 130-137 (Mar. 1959).
- Reeves, R.J.D., "The Recording and Collocation of Waveforms (Part 2)," *Electronic Engineering*, Morgan Brothers Limited, vol. 31, No. 374, pp. 204-212 (Apr. 1959).
- Rein, H.M. and Zahn, M., "Subnanosecond-Pulse Generator with Variable Pulsewidth Using Avalanche Transistors," *Electronics Letters*, IEE, vol. 11, No. 1, pp. 21-23 (Jan. 9, 1975).
- Riad, S.M. and Nehmen, N.S., "Modeling of the Feed-through Wideband (DC to 12.4 Ghz) Sampling-Head," *IEEE MTT-S International Microwave Symposium Digest*, IEEE, pp. 267-269 (Jun. 27-29, 1978).
- Rizzoli, V. et al., "Computer-Aided Noise Analysis of MESFET and HEMT Mixers," *IEEE Transactions on Microwave Theory and Techniques*, IEEE, vol. 37, No. 9, pp. 1401-1410 (Sep. 1989).
- Rowe, H.E., *Signals and Noise in Communication Systems*, D. Van Nostrand Company, Inc., Princeton, New Jersey, including, for example, Chater V, Pulse Modulation Systems (1965).
- Rücker, F. and Dintelmann, F., "Effect of Antenna Size on OTS Signal Scintillations and Their Seasonal Dependence," *Electronics Letters*, IEEE, vol. 19, No. 24, pp. 1032-1034 (Nov. 24, 1983).
- Russell, R. and Hoare, L., "Millimeter Wave Phase Locked Oscillators," *Military Microwaves '78 Conference Proceedings*, Microwave Exhibitions and Publishers, pp. 238-242 (Oct. 25-27, 1978).

## US 8,190,108 B2

Page 12

- Sabel, L.P., "A DSP Implementation of a Robust Flexible Receiver/Demultiplexer for Broadcast Data Satellite Communications," *The Institution of Engineers Australia Communications Conference*, Institution of Engineers, Australis, pp. 218-223 (Oct. 16-18, 1990).
- Salous, S., "IF digital generation of FMCW waveforms for wideband channel characterization," *IEE Proceedings-I*, IEE, vol. 139, No. 3, pp. 281-288 (Jun. 1992).
- "Sampling Loops Lock Sources to 23 Ghz," *Microwaves & RF*, Penton Publishing, p. 212 (Sep. 1990).
- Sasikumar, M. et al., "Active Compensation in the Switched-Capacitor Biquad," *Proceedings of the IEEE*, IEEE, vol. 71, No. 8, pp. 1008-1009 (Aug. 1983).
- Saul, P.H., "A GaAs MESFET Sample and Hold Switch," *Fifth European Solid State Circuits Conference—ESSCIRC 79*, IEE, pp. 5-7 (1979).
- Shen, D.H. et al., "A 900-MHz RF Front-End with Integrated Discrete-Time Filtering," *IEEE Journal of Solid-State Circuits*, IEEE Solid-State Circuits Council, vol. 31, No. 12, pp. 1945-1954 (Dec. 1996).
- Shen, X.D. and Vilar, E., "Anomalous transhorizon propagation and meteorological processes of a multilink path," *Radio Science*, American Geophysical Union, vol. 30, No. 5, pp. 1467-1479 (Sep.-Oct. 1995).
- Shen, X. and Tawfik, A.N., "Dynamic Behaviour of Radio Channels Due to Trans-Horizon Propagation Mechanisms," *Electronics Letters*, IEE, vol. 29, No. 17, pp. 1582-1583 (Aug. 19, 1993).
- Shen, X. et al., "Modeling Enhanced Spherical Diffraction and Troposcattering on a Transhorizon Path with aid of the parabolic Equation and Ray Tracing Methods," *IEE Colloquium on Common modeling techniques for electromagnetic wave and acoustic wave propagation*, IEE, pp. 4/1-4/7 (Mar. 8, 1996).
- Shen, X. and Vilar, E., "Path loss statistics and mechanisms of transhorizon propagation over a sea path," *Electronics Letters*, IEE, vol. 32, No. 3, pp. 259-261 (Feb. 1, 1996).
- Shen, D. et al., "A 900 MHz Integrated Discrete-Time Filtering RF Front-End," *IEEE International Solid State Circuits Conference*, IEEE, vol. 39, pp. 54-55 and 417 (Feb. 1996).
- Spillard, C. et al., "Z-Band Tropospheric Transhorizon Propagation Under Differing Meteorological Conditions," *Sixth International Conference on Antennas and Propagation (ICAP 89) Part 2: Propagation*, IEE, pp. 451-455 (Apr. 4-7, 1989).
- Stafford, K.R. et al., "A Complete Monolithic Sample/Hold Amplifier," *IEEE Journal of Solid-State Circuits*, IEEE, vol. SC-9, No. 6, pp. 381-387 (Dec. 1974).
- Staruk, W. Jr. et al., "Pushing HF Data Rates," *Defense Electronics*, EW Communications, vol. 17, No. 5, pp. 211, 213, 215, 217, 220 and 222 (May 1985).
- Stephenson, A.G., "Digitizing multiple RF signals requires an optimum sampling rate," *Electronics*, McGraw-Hill, Hill, pp. 106-110 (Mar. 27, 1972).
- Sugarman, R., "Sampling Oscilloscope for Statistically Varying Pulses," *The Review of Scientific Instruments*, American Institute of Physics, vol. 28, No. 11, pp. 933-938 (Nov. 1957).
- Sylvain, M., "Experimental probing of multipath microwave channels," *Radio Science*, American Geophysical Union, vol. 24, No. 2, pp. 160-178 (Mar.-Apr. 1989).
- Takano, T., "NOVEL GaAs Pet Phase Detector Operable To Ka Band," *IEEE MT-S Digest*, IEEE, pp. 381-383 (1984).
- Tan, M.A., "Biquadratic Transconductance Switched-Capacitor Filters," *IEEE Transactions on Circuits and Systems- I: Fundamental Theory and Applications*, IEEE Circuits and Systems Society, vol. 40, No. 4, pp. 272-275 (Apr. 1993).
- Tanaka, K. et al., "Single Chip Multisystem AM Stereo Decoder IC," *IEEE Transactions on Consumer Electronics*, IEEE Consumer Electronics Society, vol. CE-31, No. 3, pp. 482-196 (Aug. 1986).
- Tawfik, A.N., "Amplitude, Duration and Predictability of Long Hop Trans-Horizon X-band Signals Over the Sea," *Electronics Letters*, IEE, vol. 28, No. 6, pp. 571-572 (Mar. 12, 1992).
- Tawfik, A.N. and Vilar, E., "Correlation of Transhorizon Signal Level Strength with Localized Surface Meteorological Parameters," *Eighth International Conference on Antennas and Propagation*, Electronics Division of the IEE, pp. 335-339 (Mar. 30-Apr. 2, 1993).
- Tawfik, A.N. and Vilar, E., "Dynamic Structure of a Transhorizon Signal at X-band Over a Sea Path," *Sixth international Conference on Antennas and Propagation (ICAP 89) Part 2: Propagation*, IEE, pp. 446-450 (Apr. 4-7, 1989).
- Tawfik, A.N. and Vilar, E., "Statistics of Duration and Intensity of Path Loss in a Microwave Transhorizon Sea-Path," *Electronics Letters*, IEE, vol. 26, No. 7, pp. 474-476 (Mar. 29, 1990).
- Tawfik, A.N. and Vilar, E., "X-Band Transhorizon Measurements of CW Transmissions Over the Sea—Part 1: Path Loss, Duration of Events, and Their Modeling," *IEEE Transactions on Antennas and Propagation*, IEEE Antennas and Propagation Society, vol. 41, No. 11, pp. 1491-1500 (Nov. 1993).
- Temes, G.C. and Tsividis, T., "The Special Section on Switched-Capacitor Circuits," *Proceedings of the IEEE*, vol. 71, No. 8, pp. 915-916 (Aug. 1983).
- Thomas, G.B., *Calculus and Analytic Geometry*, Third Edition, Addison-Wesley Publishing, pp. 119-133 (1960).
- Tomassetti, Q., "An Unusual Microwave Mixer," *16th European Microwave Conference*, Microwave Exhibitions and Publishers, pp. 754-759 (Sep. 8-12, 1986).
- Tortoli, P. et al., "Bidirectional Doppler Signal Analysis Based on a Single RF Sampling Channel," *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society, vol. 41, No. 1, pp. 1-3 (Jan. 1984).
- Tsividis, Y. and Antognetti, P. (Ed.), *Design of MOS VLSI Circuits for Telecommunications*, Prentice-Hall, p. 304 (1985).
- Tsividis, Y., "Principles of Operation and Analysis of Switched-Capacitor Circuits," *Proceedings of the IEEE*, IEEE, vol. 71, No. 8, pp. 96-940 (Aug. 1983).
- Tsurumi, H. and Maeda, T., "Design Study on a Direct Conversion Receiver Front-End for 280 MHz, 900 MHz, and 2.6 Ghz Band Radio Communication Systems," *41st IEEE Vehicular Technology Conference*, IEEE Vehicular Technology Society, pp. 457-462 (May 19-22, 1991).
- Valdamanis, J.A. et al., "Picosecond and Subpicosecond Optoelectronics for Measurements of Future High Speed Electronics Devices," *IEDM Technical Digest*, IEEE, pp. 597-600 (Dec. 5-7, 1983).
- van de Kamp, M.M.J.L., "Asymmetric signal level distribution due to tropospheric scintillation," *Electronics Letters*, IEE, vol. 34, No. 11, pp. 1145-1146 (May 28, 1998).
- Vasseur, H. and Vanhoenacker, D., "Characterization of tropospheric turbulent layers from radiosonde data," *Electronics Letters*, IEE, vol. 34, No. 4, pp. 318-319 (Feb. 19, 1998).
- Verdone, R., "Outage Probability Analysis for Short-Range Communication Systems at 60 Ghz in ATT Urban Environments," *IEEE Transactions on Vehicular Technology*, IEEE Vehicular Technology Society, vol. 46, No. 4, pp. 1027-1039 (Nov. 1997).
- Vierira-Ribeiro, S.A., *Single-IF DECT Receiver Architecture using a Quadrature Sub-Sampling Band-Pass Sigma-Delta Modulator*, Thesis for Degree of Master's of Engineering, Carleton University, UMI Dissertation Services, pp. 1-180 (Apr. 1995).
- Vilar, E. et al., "A Comprehensive/Selective MM-Wave Satellite Downlink Experiment on Fade Dynamics," *Tenth International Conference on Antennas and Propagation*, Electronics Division of the IEE, pp. 2.98-2.101 (Apr. 14-17, 1997).
- Vilar, E. et al., "A System to Measure LOS Atmospheric Transmittance at 19 Ghz," *AGARD Conference Proceedings No. 346: Characteristics of the Lower Atmosphere Influencing Radio Wave Propagation* AGARD, pp. 8-1-8-16 (Oct. 4-7, 1983).
- Vilar, E. and Smith, H., "A Theoretical and Experimental Study of Angular Scintillations in Earth Space Paths," *IEEE Transactions on Antennas and Propagation*, IEEE, vol. AP-34, No. 1, pp. 2-10 (Jan. 1986).
- Vilar, E. et al., "A Wide Band Transhorizon Experiment at 11.6 Ghz," *Eighth International Conference on Antennas and Propagation*, Electronics Division of the IEE, pp. 441-445 (Mar.30-Apr. 2, 1993).
- Vilar, E. and Matthews, P.A., "Amplitude Dependence of Frequency in Oscillators," *Electronics Letters*, IEE, vol. 8, No. 20, pp. 509-511 (Oct. 5, 1972).

## US 8,190,108 B2

Page 13

- Vilar, E. et al., "An experimental mm-wave receiver system for measuring phase noise due to atmospheric turbulence," *Proceedings of the 25<sup>th</sup> European Microwave Conference*, Nexus House, pp. 114-119 (1995).
- Vilar, E. and Burguño, A., "Analysis and Modeling of Time Intervals Between Rain Rate Exceedances in the Context of Fade Dynamics," *IEEE Transactions on Communications*, IEEE Communications Society, vol. 39, No. 9, pp. 1306-1312 (Sep. 1991).
- Vilar, E. et al., "Angle of Arrival Fluctuations in High and Low Elevation Earth Space Paths," *Fourth International Conference on Antennas and Propagation (ICAP 85)*, Electronics Division of the IEE, pp. 83-88 (Apr. 16-19, 1985).
- Vilar, E., "Antennas and Propagation: A Telecommunications Systems Subject," *Electronics Division Colloquium on Teaching Antennas and Propagation to Undergraduates*, IEE, pp. 7/1-7/1 (Mar. 8, 1988).
- Vilar, E. et al., "CERS\*. Millimetre-Wave Beacon Package and Related Payload Doppler Correction Strategies," *Electronics Division Colloquium on CERS—Communications Engineering Research Satellite*, IEE, pp. 10/1-10/10 (Apr. 10, 1984).
- Vilar, E. and Mousley, T.J., "Comment and Reply: Probability Density Function of Amplitude Scintillations," *Electronics Letters*, IEE, vol. 21, NO. 14, pp. 620-622 (Jul. 4, 1985).
- Vilar, E. et al., "Comparison of Rainfall Rate Duration Distributions for ILE-IFE and Barcelona," *Electronics Letters*, IEE, vol. 28, No. 20, pp. 1922-1924 (Sep. 24, 1992).
- Vilar, E., "Depolarization and Field Transmittances in Indoor Communications," *Electronics Letters*, IEE, vol. 27, No. 9, pp. 732-733 (Apr. 25, 1991).
- Vilar, E. and Larsen, J.R., "Elevation Dependence of Amplitude Scintillations on Low Elevation Earth Space Paths," *Sixth International Conference on Antennas and Propagation (ICAP 89) Part 2: Propagation*, IEE, pp. 150-154 (Apr. 4-7, 1989).
- Vilar, E. et al., "Experimental System and Measurements of Transhorizon Signal Levels at 11 Ghz," *18<sup>th</sup> European Microwave Conference*, Microwave Exhibitions and Publishers Ltd., pp. 429-435 (Sep. 12-15, 1988).
- Vilar, E. and Matthews, P.A., "Importance of Amplitude Scintillations in Millimetric Radio Links," *Proceedings of the 4<sup>th</sup> European Microwave Conference*, Microwave Exhibitions and Publishers, pp. 202-206 (Sep. 10-13, 1974).
- Vilar, E. and Haddon, J., "Measurement and Modeling of Scintillation Intensity to Estimate Turbulence Parameters in an Earth-Space Path," *IEEE Transactions on Antennas and Propagation*, IEEE Antennas and Propagation Society, vol. AP-32, No. 4, pp. 340-346 (Apr. 1984).
- Vilar, E. and Matthews, P.A., "Measurement of Phase Fluctuations on Millimetric Radiowave Propagation," *Electronics Letters*, IEE, vol. 7, No. 18, pp. 566-568 (Sep. 9, 1971).
- Vilar, E. and Wan, K.W., "Narrow and Wide Band Estimates of Field Strength for Indoor Communications in the Millimetre Band," *Electronics Division Colloquium on Radiocommunications in the Range 30-60 Ghz*, IEEE, pp. 5/1-5/8 (Jan. 17, 1991).
- Vilar, E. and Faulkner, N.D., "Phase Noise and Frequency Stability Measurements. Numerical Techniques and Limitations," *Electronics Division Colloquium on Low Noise Oscillators and Synthesizer*, IEE, 5 pages (Jan. 23, 1986).
- Vilar, E. and Senin, S., "Propagation phase noise identified using 40 Ghz satellite downlink," *Electronics Letters*, IEE, vol. 33, No. 22, pp. 1901-1902 (Oct. 23, 1997).
- Vilar, E. et al., "Scattering and Extinction: Dependence Upon Rain-drop Size Distribution in Temperate (Barcelona) and Tropical (Belem) Regions," *Tenth international Conference on Antennas and Propagation*, Electronics Division of the IEE, pp. 2,230-2,233 (Apr. 14-17, 1997).
- Vilar, E. and Haddon, J., "Scintillation Modeling and Measurement—A Tool for Remote-Sensing Slant Paths," *AGARD Conference Proceedings No. 332. Propagation Aspects of Frequency Sharing, interference and System Diversity*, AGARD, pp. 27-1-27-13 (Oct. 18-22, 1982).
- Vilar, E., "Some Limitations on Digital Transmissin Through Turbulent Atmosphere," *International Conference on Satellite Communication Systems Technology*, Electronics Division of the IEE, pp. 169-187 (Apr. 7-10, 1975).
- Vilar, E. and Matthews, P.A., "Sumamry of Scintillation Observations in a 36 Ghz Link Across London," *International Conference on Antennas and Propagation Part 2: Propagation*, IEE, pp. 36-40 (Nov. 28-30, 1978).
- Vilar, E. et al., "Wideband Characterization of Scattering Channels," *Tenth International Conference on Antennas and Propagation*, Electronics Division of the IEE, pp. 2,353-2,358 (Apr. 14-17, 1997).
- Vollmer, A., "Complete GPS Receiver Fits on Two Chips," *Electronic Design*, Penton Publishing, pp. 50, 52, 54 and 56 (Jul. 6, 1998).
- Voltage and Time Resolution in Digitizing Oscilloscopes: Application Note 348, Hewlett Packard, pp. 1-11 (Nov. 1986).
- Wan, K.W. et al., "A Novel Approach to the Simultaneous Measurement of Phase and Amplitude Noises in Oscillator," *Proceedings of the 19<sup>th</sup> European Microwave Conference*, Microwave Exhibitions and Publishers Ltd., pp. 809-813 (Sep. 4-7, 1989).
- Wan, K.W. et al., "Extended Variances and Autoregressive/Moving Average Algorithm for the Measurement and Synthesis of Oscillator Phase Noise," *Proceedings of the 43<sup>rd</sup> Annual Symposium on Frequency Control*, IEEE, pp. 331-335 (1989).
- Wan, K.W. et al., "Wideband Trashorizon Channel Sounder at 11 Ghz," *Electronics Division Colloquium on High Bite Rate UHF/SHF Channel Soundrs—Technology and Measurement*, IEEE pp. 3/1-3/5 (Dec. 3, 1993).
- Wang, H., "A 1-V Multigigahertz RF Mixer Core in 0.5- $\mu$ m CMOS," *IEEE Journal of solid-State Circuits*, IEEE Solid-State Circuits Society, vol. 33, No. 12, pp. 2265-2267 (Dec. 1998).
- Watson, A.W.D. et al., "Digital Conversin and Signal Processing for High Performance Communications Receivers," *Digital Processing of Signals in Communications*, Institution of Electronic and Radio Engineers, pp. 367-373 (Apr. 22-26, 1985).
- Weast, R.C. et al. (Ed.), *Handbook of Mathematical Tables*, Second Edition, The Chemical Rubber Co., pp. 480-485 (1964).
- Wiley, R.G., "Approximate FM Demodulation Using Zero Crossings," *IEEE Transactons on Communications*, IEEE, vol. COM-29, No. 7, pp. 1061-1065 (Jul. 1981).
- Worthman, W., "Convergence . . . Again," *RF Design*, Primedia, p. 102 (Mar. 1999).
- Young, I.A. and Hodges, D.A., "MOS Switched-Capacitor Analog Sampled-Data Direct-Form Recursive Filters," *IEEE Journal of Solid-State Circuits*, IEEE, vol. SC-14, No. 6, pp. 1020-1033 (Dec. 1979).
- Translation of Specification and Claims of FR Patent No. 2245130, 3 pages (Apr. 18, 1975—Date of publication of application).
- Fest, Jean-Pierre, "Le Convertisseur A/N Revolutionne Le Recepteur Radio," *Electronique*, JMJ (Publisher), No. 54, pp. 40-42 (Dec. 1995).
- Translation of DE Patent No. 35 41 031 A1, 22 pages (May 22, 1986—Date of publication of application).
- Translation of EP Patent No. 0 732 803 A1, 9 pages (Sep. 18, 1996—Date of publication of application).
- Fest, Jean-Pierre, "The A/D Converter Revolutionizes the Radio Receiver," *Electronique*, JMJ (Publisher), No. 54, 3 pages (Dec. 1995). (Translation of Doc. AQ50).
- Translation of German Patent No. DE 197 35 798 C1, 8 pages (Jul. 16, 1998—Date of publication of application).
- Miki, S. and Nagahama, R., *Modulation System II*, Common Edition 7, Kyoritsu Publishing Co., Ltd., pp. 146-154 (Apr. 30, 1956).
- Miki, S. and Nagahama, R., *Modulation System II*, Common Edition 7, Kyoritsu Publishing Co., Ltd., pp. 146-149 (Apr. 30, 1956). (Partial Translation of Doc. AQ51).
- Rabiner, L.R. and Gold, B., *Theory and Application of Digital Signal Processing*, Prentice-Hall, Inc., pp. v-xii and 40-46 (1975).
- English-language Abstract of Japanese Patent Publication No. 08-032556, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Feb. 2, 1996—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 08-139524, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (May 31, 1996—Date of publication of application).

## US 8,190,108 B2

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- English-language Abstract of Japanese Patent Publication No. 59-144249, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Aug. 18, 1984—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 63-054002, from <http://www1.ipdl.jpo.go.jp>, 2 Pages Mar. 8, 1988—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 06-237276, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Aug. 23, 1994—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 08-023359, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Jan. 23, 1996—Date of publication of application).
- Translation of Japanese Patent Publication No. 47-2314, 7 pages (Feb. 4, 1972—Date of publication of application).
- Partial Translation of Japanese Patent Publication No. 58-7903, 3 pages (Jan. 17, 1983—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 568-133004, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Aug. 8, 1993—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 60-058705, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Apr. 4, 1985—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 04-123614, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Apr. 23, 1992—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 04-127601, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Apr. 28, 1992—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 05-175730, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Jul. 13, 1993—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 05-175734, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Jul. 13, 1993—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 07-154344, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Jun. 16, 1995—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 07-307620, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Nov. 21, 1995—Date of publication of application).
- Oppenheim, A.V. and Schaffer, R.W., *Digital Signal Processing*, Prentice-Hall, pp. vii-x, 6-35, 45-78, 87-121 and 136-165 (1975).
- English-language Abstract of Japanese Patent Publication No. 55-066057, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (May 19, 1980—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 63-065587, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Mar. 24, 1988—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 63-153691, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Jun. 27, 1988—Date of publication of application).
- Translation of Japanese Patent Publication No. 60-130203, 3 pages (Jul. 11, 1985—Date of publication of application).
- Razavi, B., "A 900-MHz/1.8-GHz CMOS Transmitter for Dual-Band Applications," *Symposium on VLSI Circuits Digest of Technical Papers*, IEEE, pp. 128-131 (1998).
- Ritter, G.M., "SDA, A New Solution for Transceivers," *16th European Microwave Conference*, Microwave Exhibitors and Publishers pp. 729-733 (Sep. 8, 1986).
- DIALOG File 351 (Derwent WPI) English Language Patent Abstract for FR 2 669 787, 1 page (May 29, 1992—Date of publication of application).
- Akos, D.M. et al., "Direct Bandpass Sampling of Multiple Distinct RF Signals," *IEEE Transactions on Communications*, IEEE, vol. 47, No. 7, pp. 983-988 (Jul. 1999).
- Patel, M. et al., "Bandpass Sampling for Software Radio Receivers, and the Effect of Oversampling on Aperture Jitter," *VTC 2002*, IEEE, pp. 1901-1905 (2002).
- English-language Abstract of Japanese Patent Publication No. 61-030821, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Feb. 13, 1986—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. 05-327356, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Dec. 10, 1993—date of publication of application).
- Taylor, D., "A Low-noise, High-performance Zero IF Quadrature Detector/Preamplifier," *RF Design*, Primedia Business Magazines & Media, Inc., pp. 58, 60, 62 and 69 (Mar. 2003).
- Dines, J.A.B., "Smart Pixel Optoelectronic Receiver Based on a Charge Sensitive Amplifier Design," *IEEE Journal of Selected Topics in Quantum Electronics*, IEEE, vol. 2, No. 1, pp. 117-120 (Apr. 1996).
- Simoni, A. et al., "A Digital Camera for Machine Vision," *20th International Conference on Industrial Electronics, Control and Instrumentation*, IEEE, pp. 879-883 (Sep. 1994).
- Stewart, R.W. and Pfann, E., "Oversampling and sigma-delta strategies for data conversion," *Electronics & Communication Engineering Journal*, IEEE, pp. 37-47 (Feb. 1998).
- Rudeil, J.C. et al., "A 1.9-GHz Wide-Band IF Double Conversion CMOS Receiver for Cordless Telephone Applications," *IEEE Journal of Solid-State Circuits*, IEEE, vol. 32, No. 12, pp. 2071-2088 (Dec. 1997).
- English-language Abstract of Japanese Patent Publication No. 09-036664, from <http://www1.ipdl.jpo.go.jp>, 2 Pages (Feb. 7, 1997—Date of publication of application).
- Simoni, A. et al., "A Single-Chip Optical Sensor with Analog Memory for Motion Detection," *IEEE Journal of Solid-State Circuits*, IEEE, vol. 30, No. 7, pp. 800-806 (Jul. 1995).
- English Translation of German Patent Publication No. DE 196 48 915 A1, 10 pages.
- Deboo, Gordon J., *Integrated Circuits and Semiconductor Devices*, 2nd Edition, McGraw-Hill, Inc., pp. 41-45 (1977).
- Hellwarth, G.A. and Jones, G.D., "Automatic Conditioning of Speech Signals," *IEEE Transactions on Audio and Electroacoustics*, vol. AU-16, No. 2, pp. 169-179 (Jun. 1968).
- English Abstract for German Patent No. DE 692 21 098 T2, 1 page, data supplied from the espacenet.
- Gaudiosi, J., "Retailers will bundle Microsoft's Xbox with games and peripherals," *Video Store Magazine*, vol. 23, Issue 36, p. 8, 2 pages (Sep. 2-8, 2001).
- English-language Translation of German Patent Publication No. DT 1936252, translation provided by Transperfect Translations, 12 pages (Jan. 28, 1971—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 62-12381, data supplied by the espacenet, 1 page (Jan. 21, 1987—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 4-154227, data supplied by the espacenet, 1 page (May 27, 1992—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 6-284038, data supplied by the espacenet, 1 page (Oct. 7, 1994—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 10-96778, data supplied by the espacenet, 1 page (Apr. 14, 1998—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 11-98205, data supplied by the espacenet, 1 page (Apr. 9, 1999—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 61-232706, data supplied by the espacenet, 1 page (Oct. 17, 1986—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 9-171399, data supplied by the espacenet, 1 page (Jun. 30, 1997—Date of publication of application).
- English-language Abstract of Japanese Patent Publication No. JP 10-41860, data supplied by the espacenet, 1 page (Feb. 13, 1998—Date of publication of application).
- English-language Computer Translation of Japanese Patent Publication No. JP 10-41860, provided by the JPO (Jun. 26, 1998—Date of publication of application) and cited in U.S. Appl. No. 10/305,299, directed to related subject matter.
- What is I/Q Data?*, printed Sep. 16, 2006, from <http://zone.ni.com>, 8 pages (Copyright 2003).

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English-language Abstract of Japanese Patent Publication No. JP 58-031622, data supplied by ep.espacenet.com, 1 page (Feb. 24, 1983—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 61-245749, data supplied by ep.espacenet.com, 1 page (Nov. 1, 1986—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 64-048557, data supplied by ep.espacenet.com, 1 page (Feb. 23, 1989—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 59-022438, data supplied by ep.espacenet.com, 1 page (Feb. 4, 1984—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 59-123318, data supplied by ep.espacenet.com, 1 page (Jul. 17, 1984—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 61-193521, data supplied by ep.espacenet.com, 1 page (Aug. 28, 1986—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 62-047214, data supplied by ep.espacenet.com, 1 page (Feb. 28, 1987—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 63-274214, data supplied by ep.espacenet.com, 1 page (Nov. 11, 1988—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 7-169292, data supplied by ep.espacenet.com, 1 page (Jul. 4, 1995—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 10-22804, data supplied by ep.espacenet.com, 1 page (Jan. 23, 1998—Date of publication of application).

English-language Abstract of Japanese Patent Publication No. JP 8-288682, data supplied by ep.espacenet.com, 1 page (Nov. 1, 1996—Date of publication of application).

Office Communication, dated May 20, 2008, for U.S. Appl. No. 11/826,416, filed Jul. 16, 2007, 5 pages.

Office Communication, dated Oct. 24, 2008, for U.S. Appl. No. 11/826,416, filed Jul. 16, 2007, 5 pages.

Notice of Allowance dated Feb. 16, 2012 cited in U.S. Appl. No. 12/881,912, filed Sep. 14, 2010.

Office action dated Jan. 13, 2012 cited in U.S. Appl. No. 12/615,326, filed Nov. 10, 2009.

Office Action dated Dec. 14, 2011 cited in U.S. Appl. No. 12/634,233, filed Dec. 9, 2009.

Notice of Allowance dated Dec. 20, 2011 cited in U.S. Appl. No. 11/589,921, filed Oct. 31, 2006.

Office Action dated May 26, 2011 cited in U.S. Appl. No. 11/589,921, filed Oct. 31, 2006.

Office Action dated Oct. 6, 2011 cited in U.S. Appl. No. 12/118,111, filed May 9, 2008.

Notice of Allowance dated Jan. 20, 2012 cited in U.S. Appl. No. 12/881,912, filed Sep. 14, 2010.

Notice of Allowance dated Feb. 29, 2012 cited in U.S. Appl. No. 11/589,921, filed Oct. 31, 2006.

\* cited by examiner

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FIG. 1  
(RELATED ART)

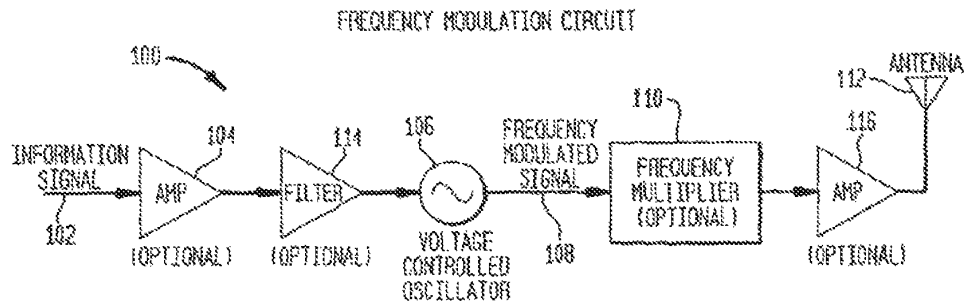


FIG. 2A  
(RELATED ART)

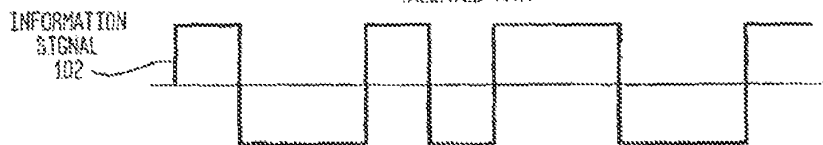


FIG. 2B  
(RELATED ART)

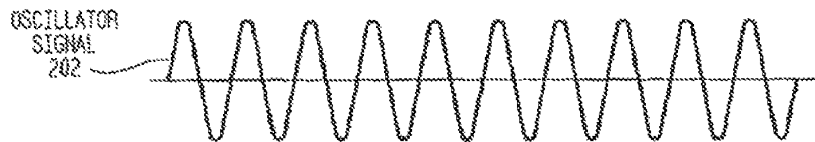


FIG. 2C  
(RELATED ART)

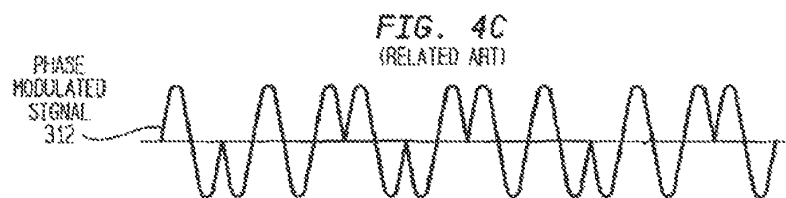
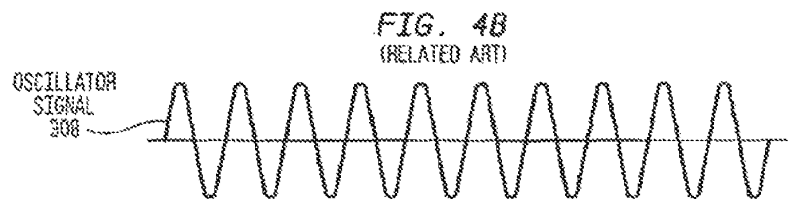
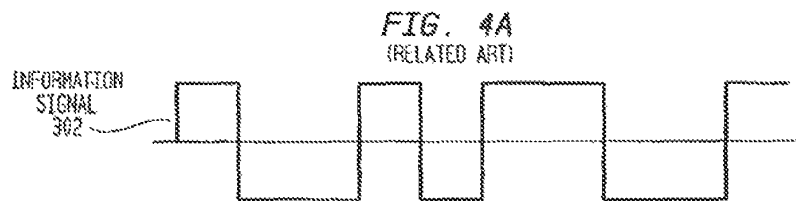
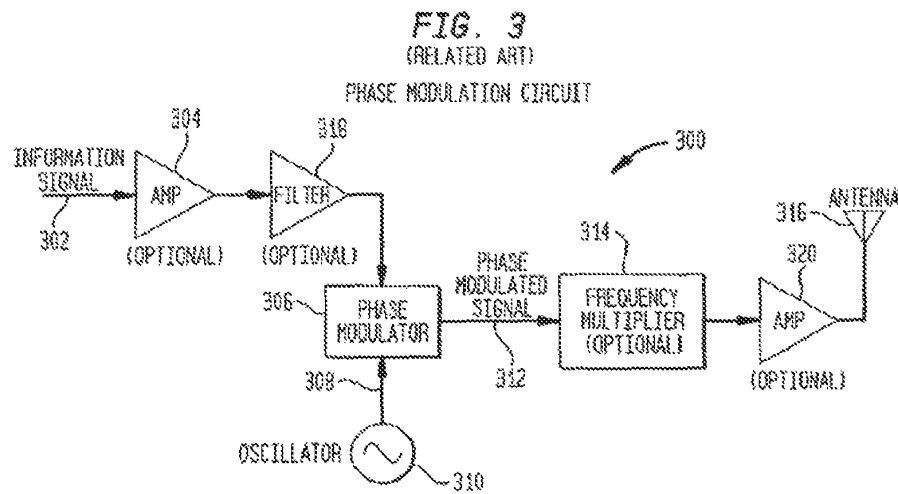


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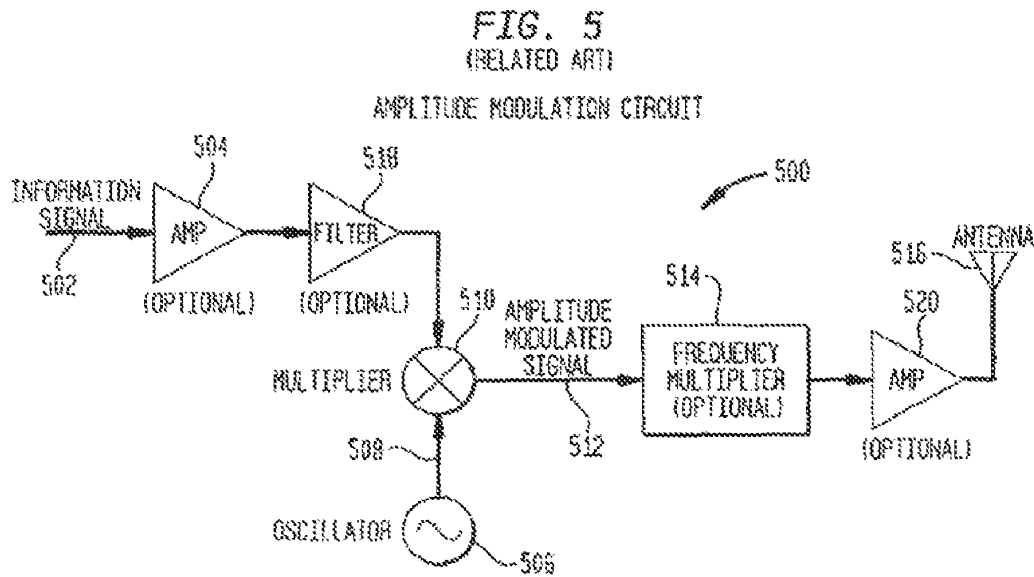


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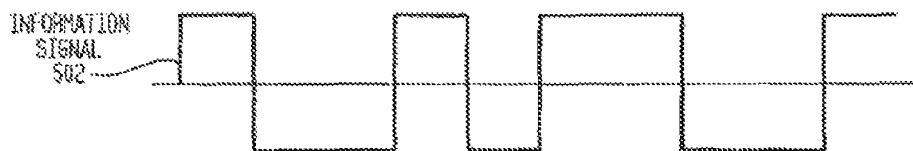
**U.S. Patent**

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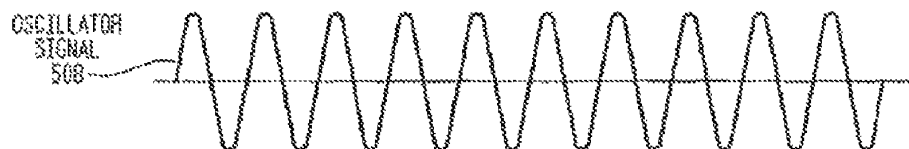
Sheet 4 of 59

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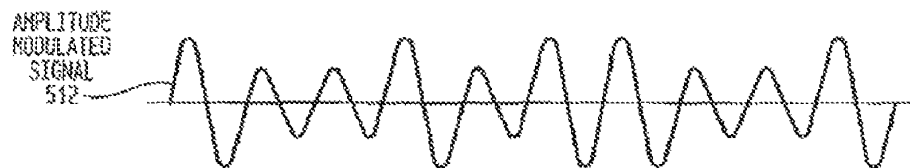
*FIG. 6A*  
(RELATED ART)



*FIG. 6B*  
(RELATED ART)



*FIG. 6C*  
(RELATED ART)

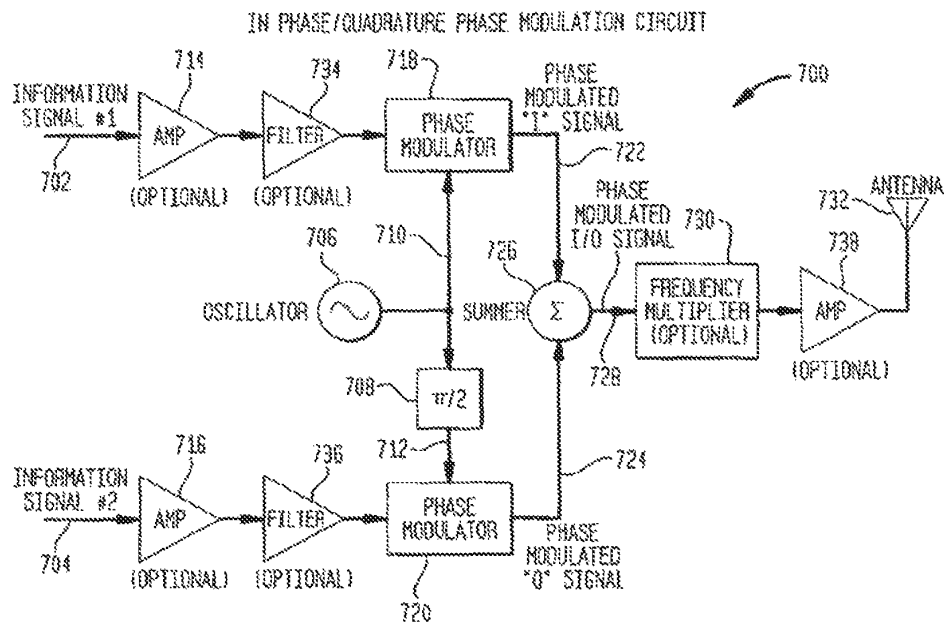


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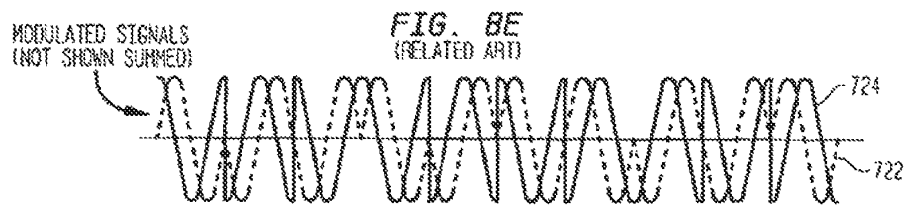
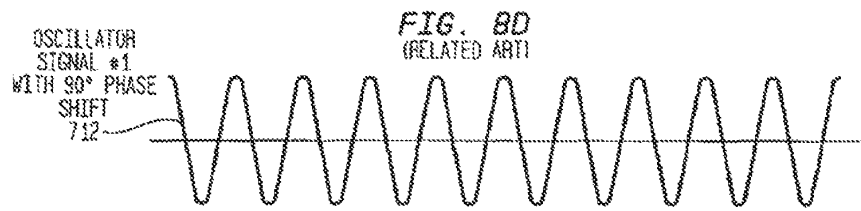
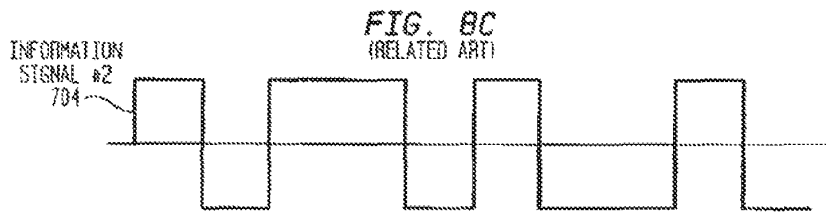
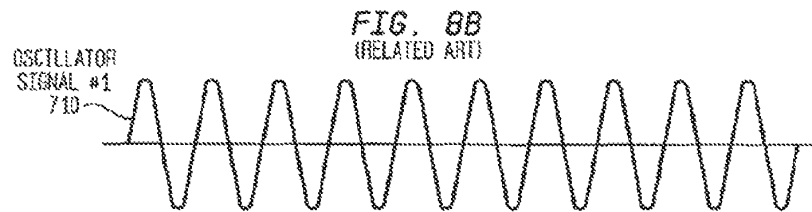
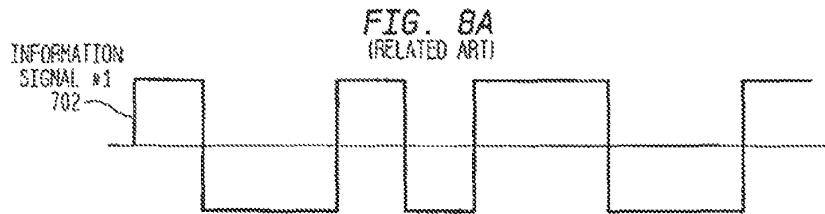
FIG. 7  
(RELATED ART)

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FIG. 9

TRANSMITTER

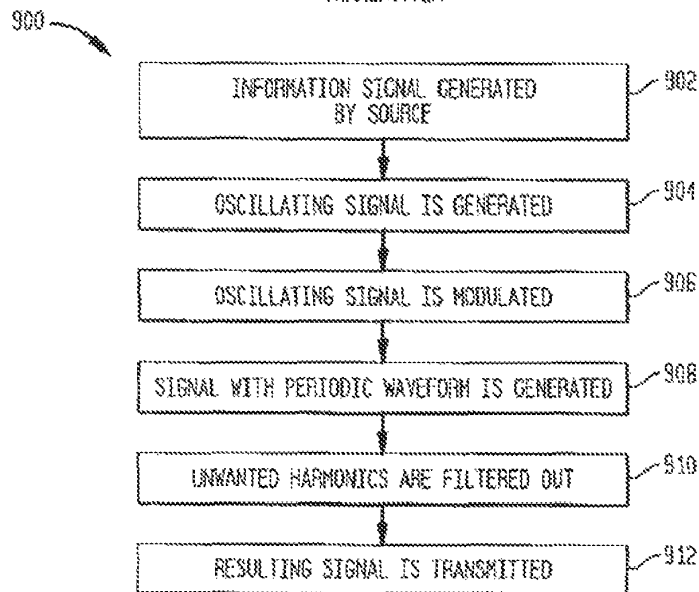
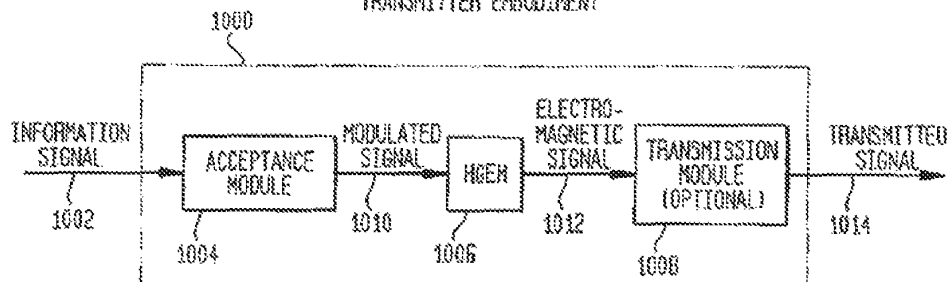


FIG. 10

TRANSMITTER EMBODIMENT



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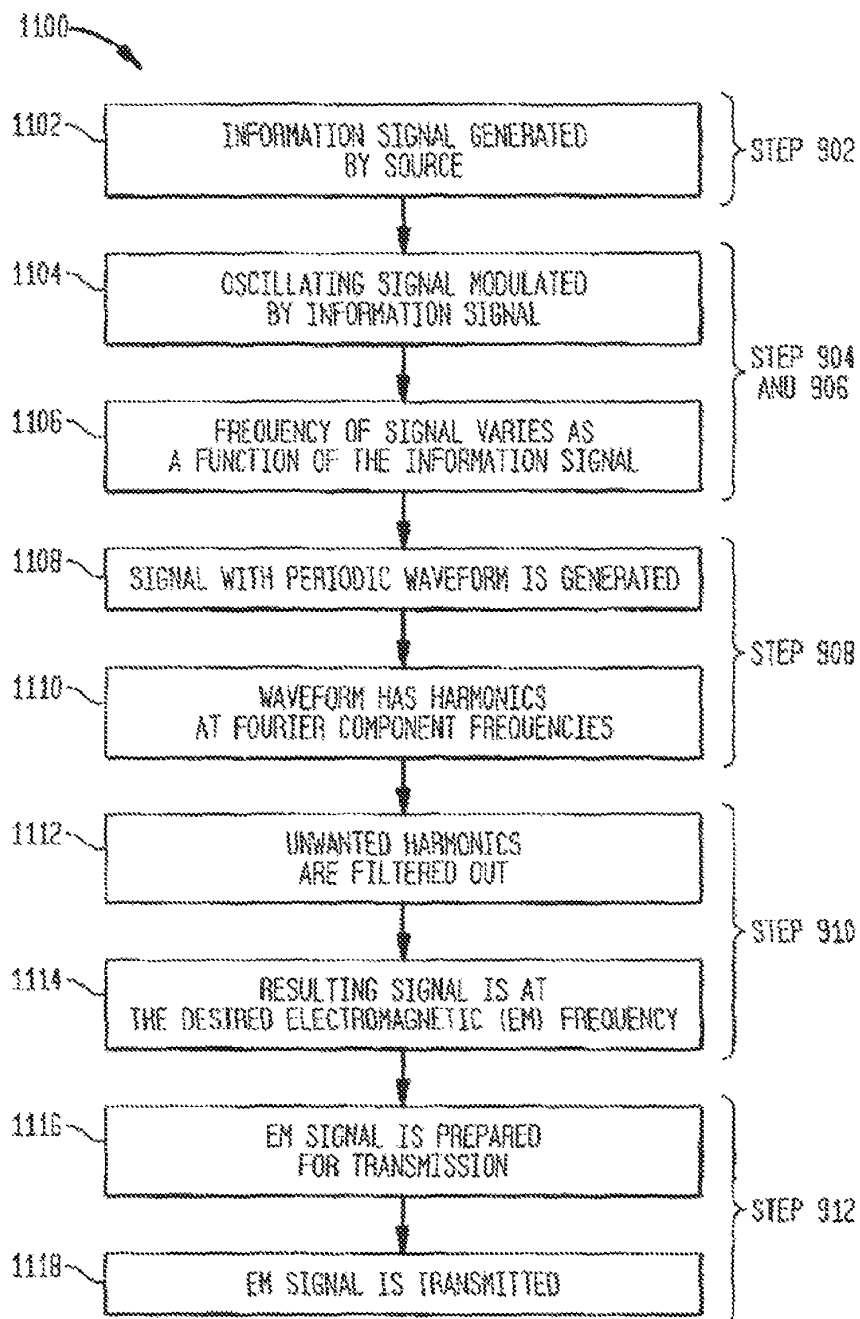
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**FIG. 11**

FREQUENCY MODULATION MODE



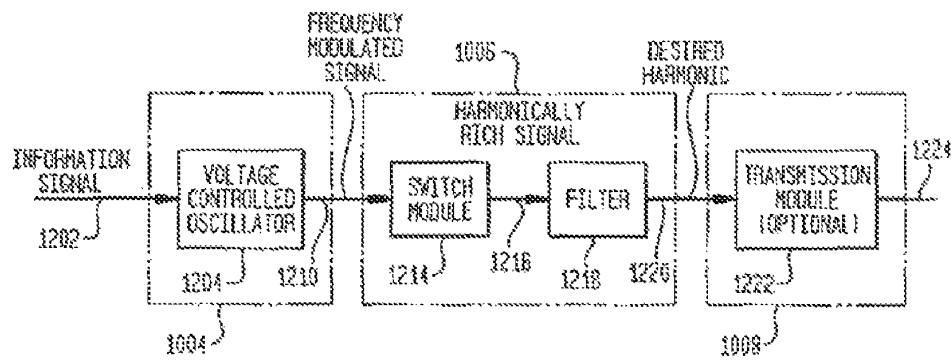
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FIG. 12



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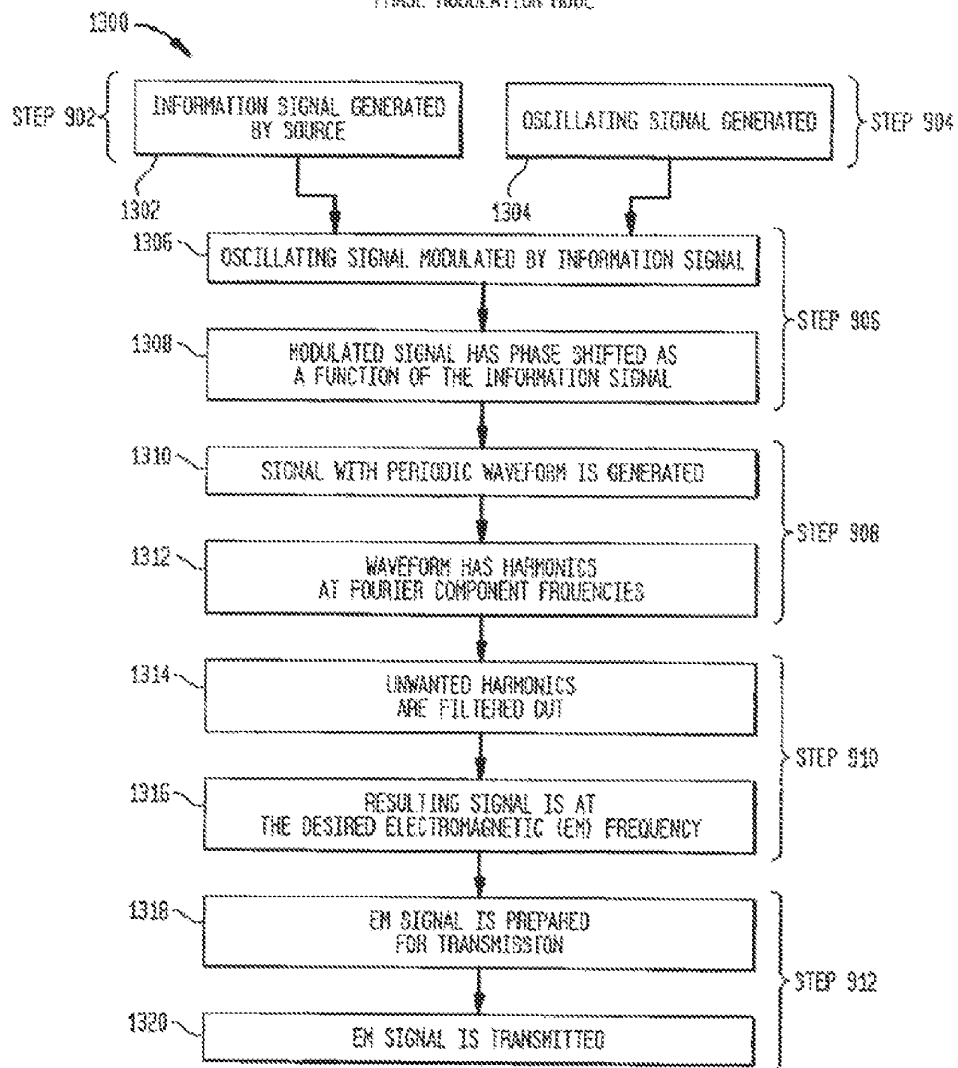
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FIG. 13

PHASE MODULATION MODE



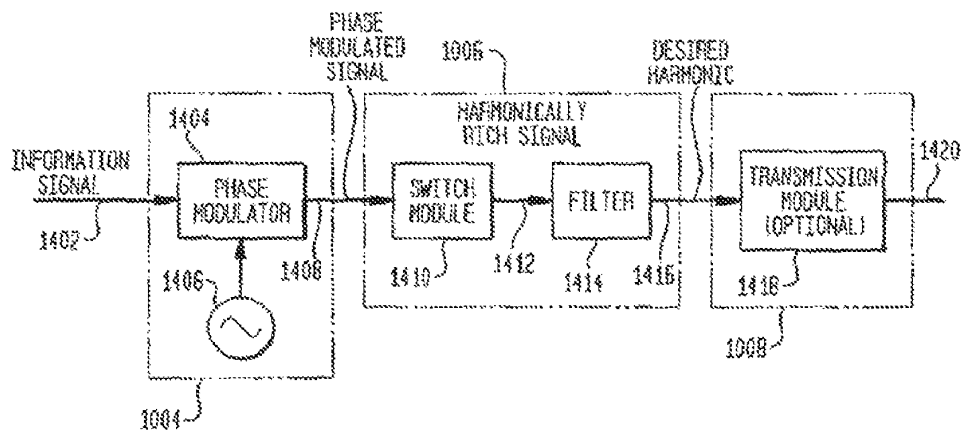
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FIG. 14



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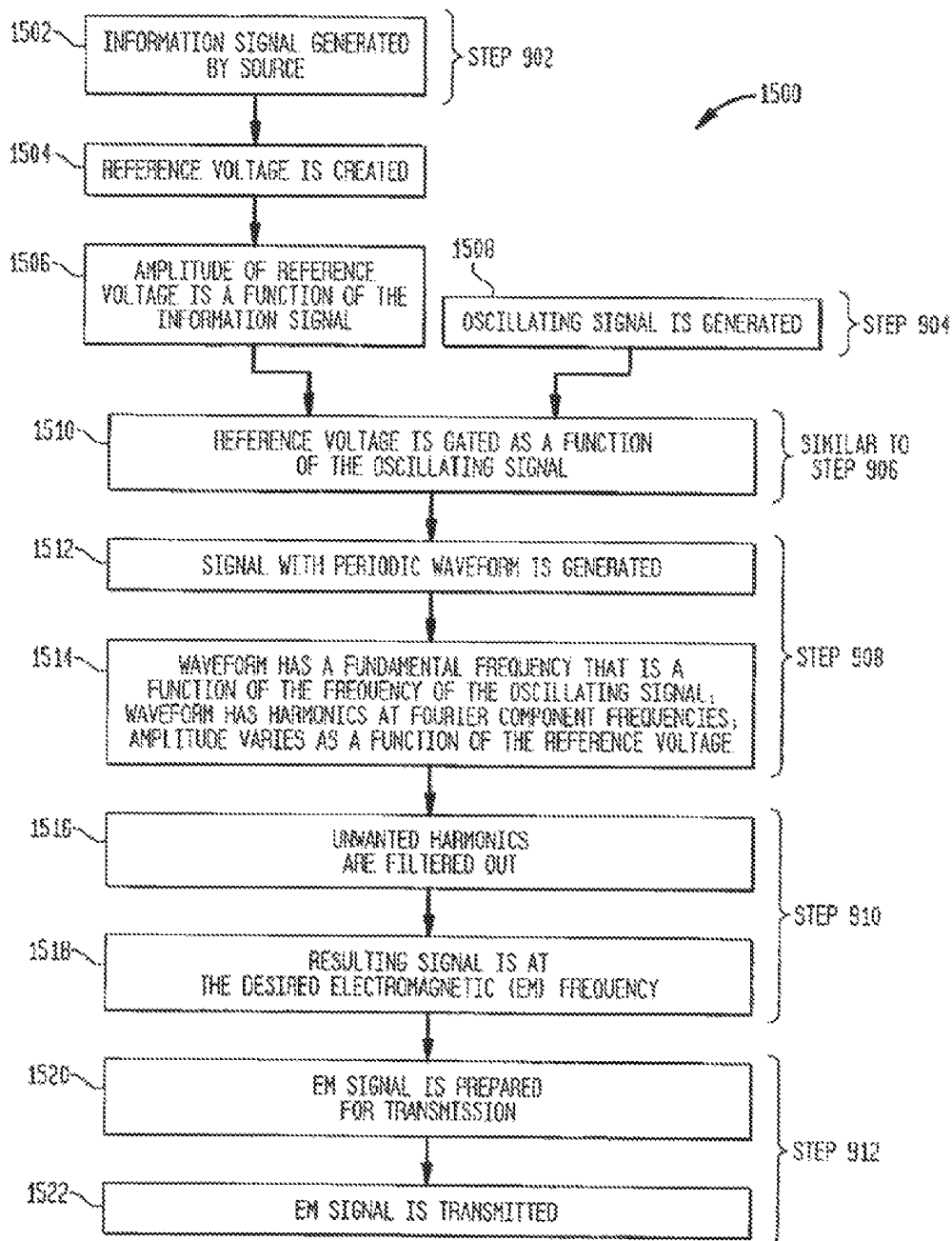
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FIG. 15

AMPLITUDE MODULATION MODE



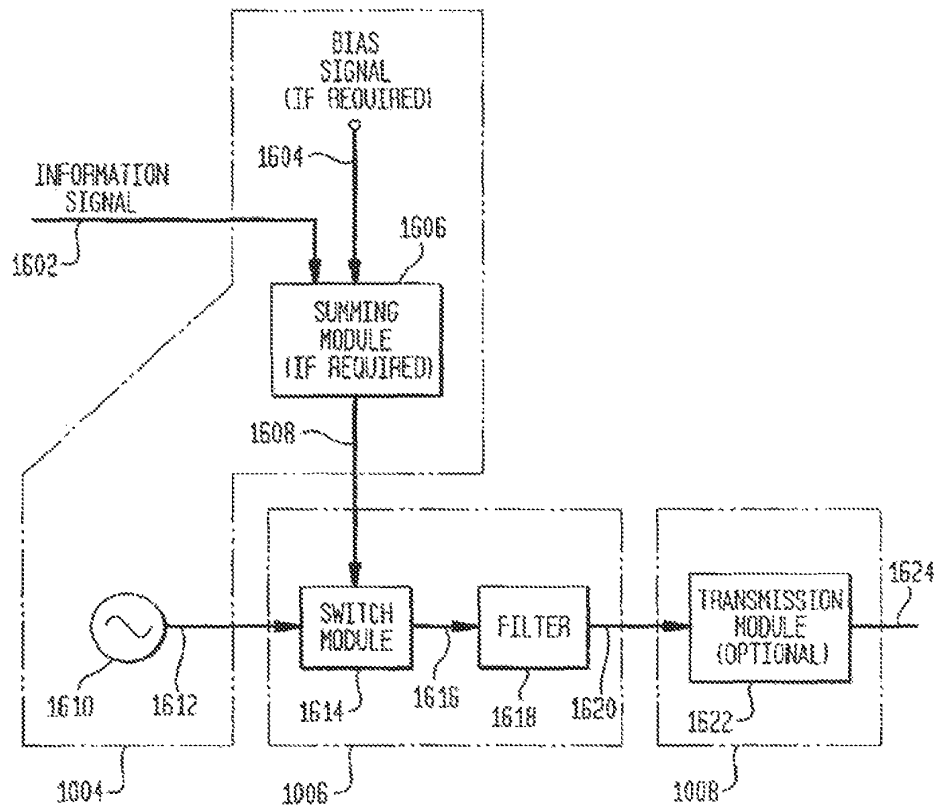
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FIG. 16



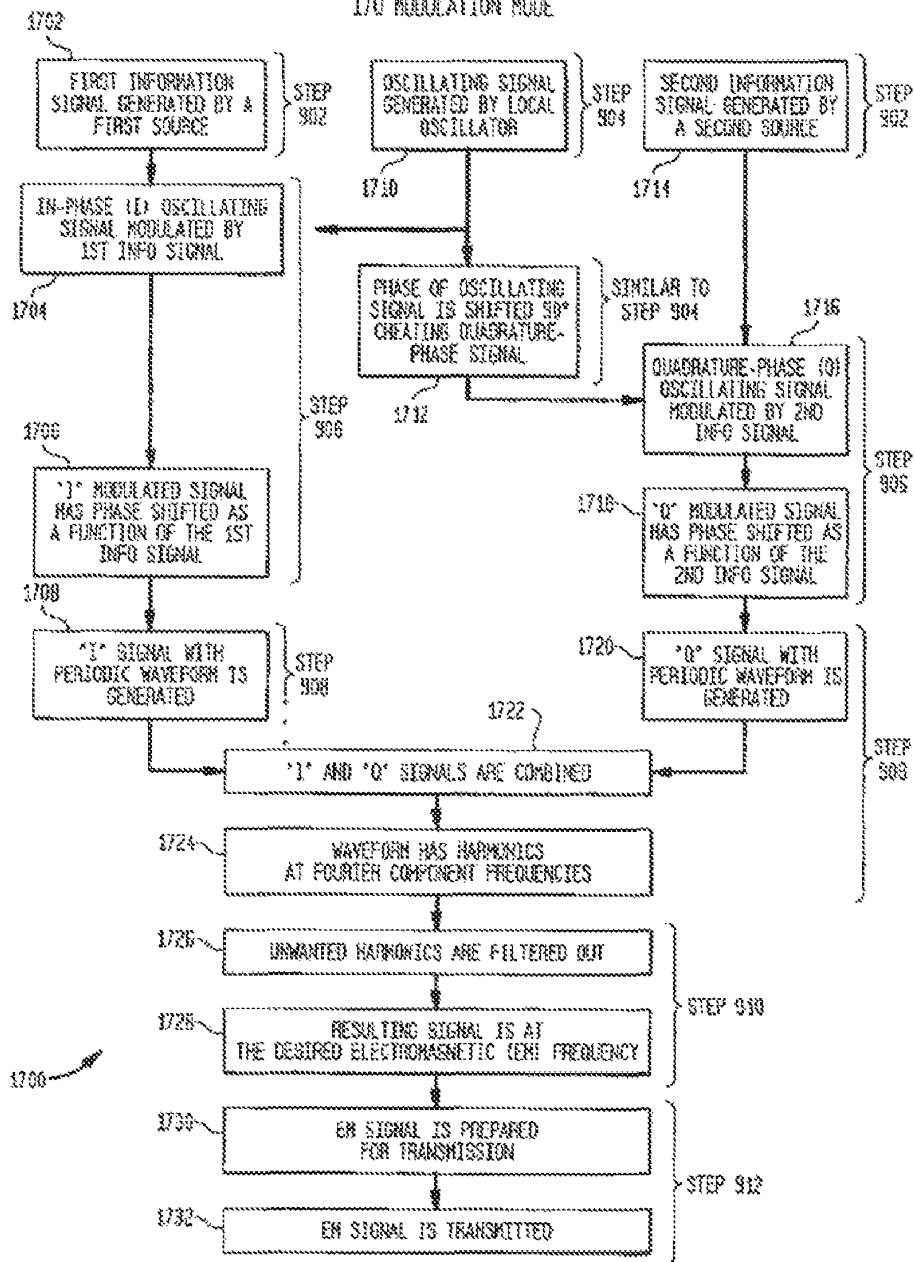
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FIG. 17  
I/O MODULATION MODE



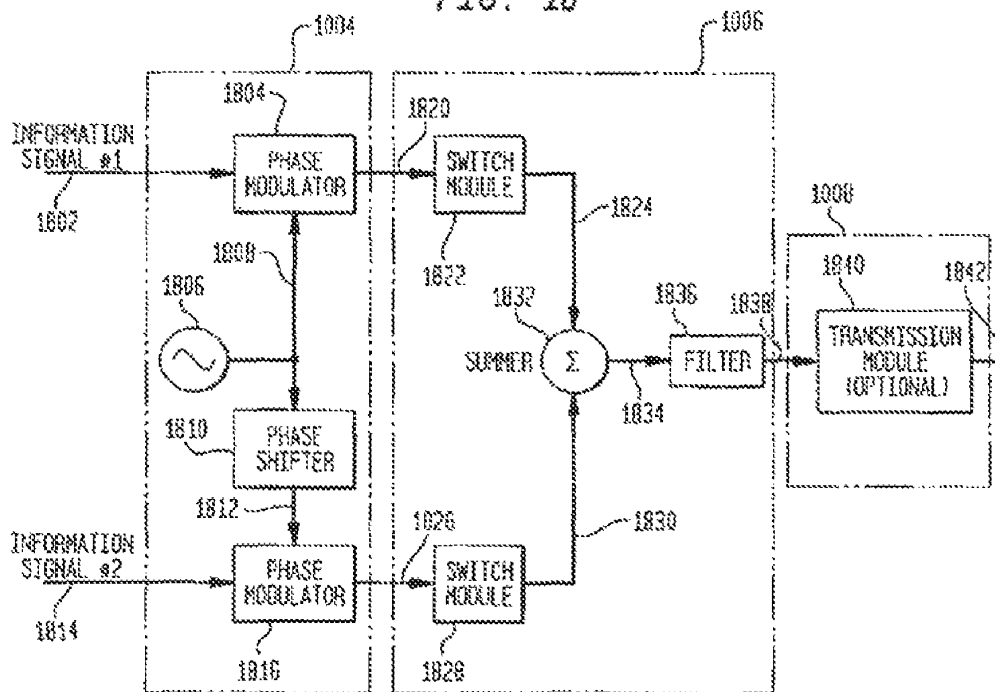
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FIG. 18



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FIG. 19A

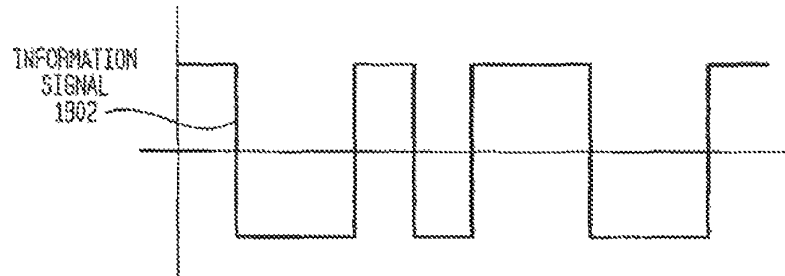


FIG. 19B

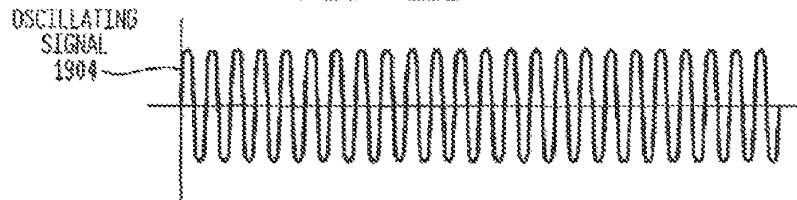


FIG. 19C

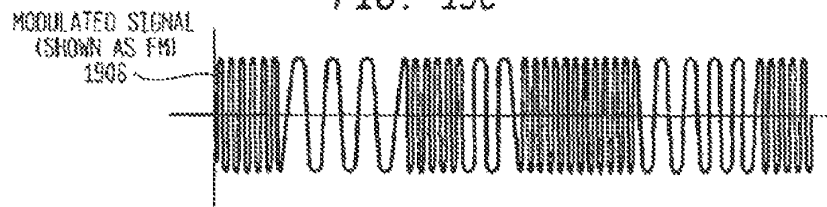
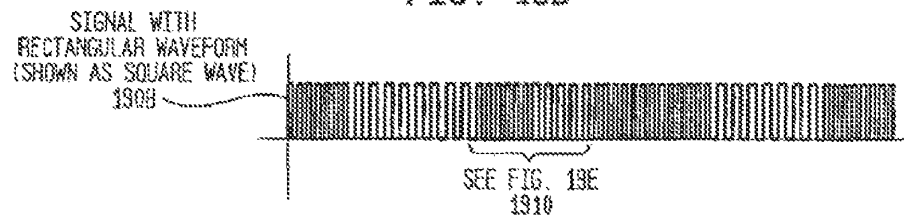


FIG. 19D

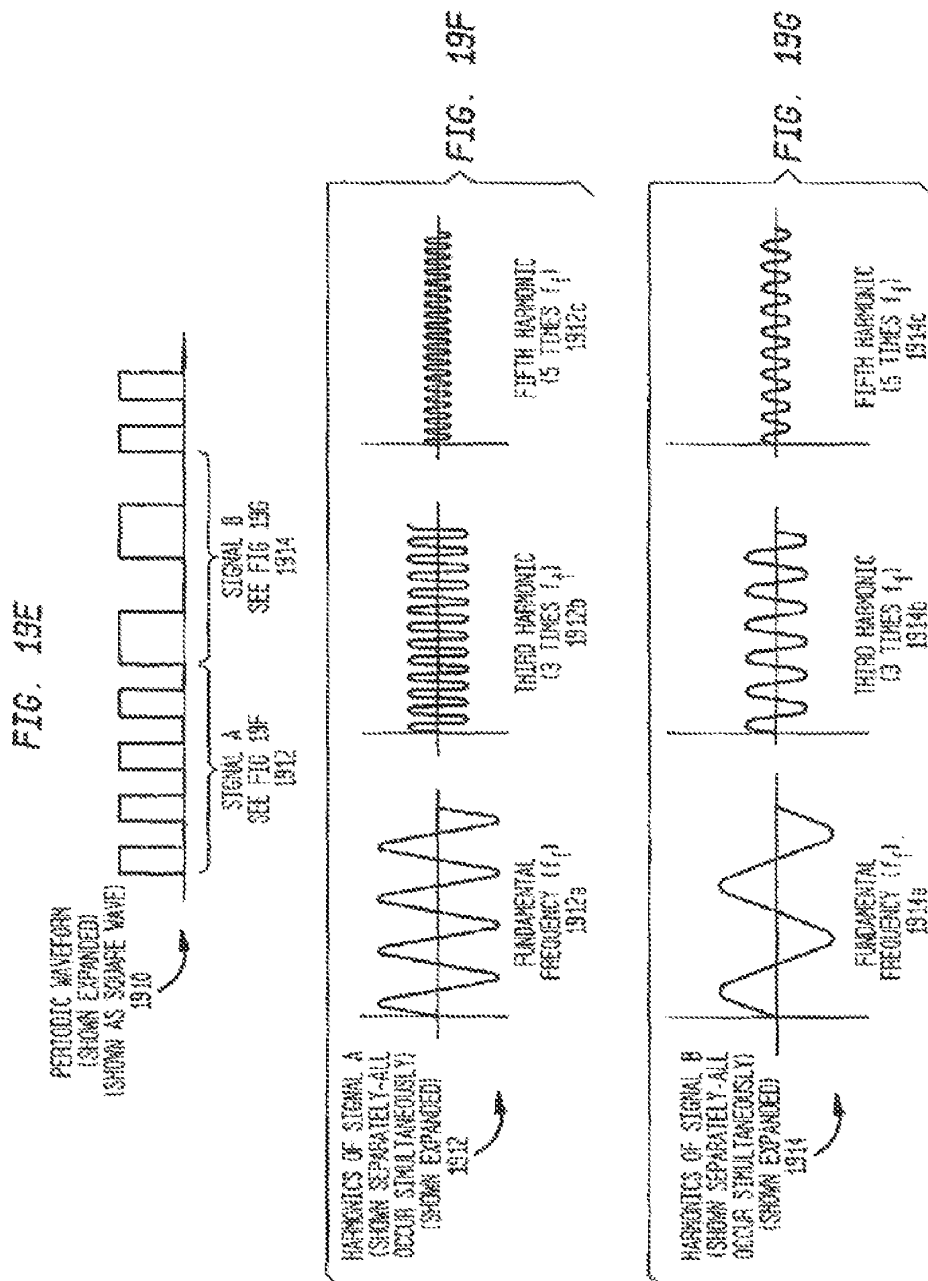


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FIG. 19H

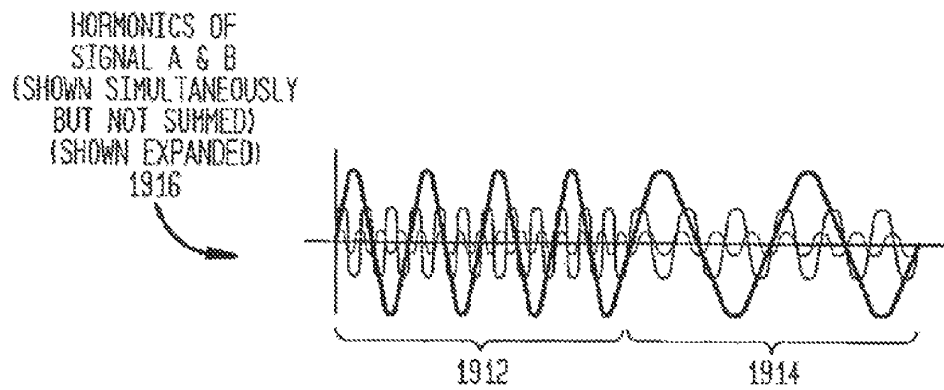
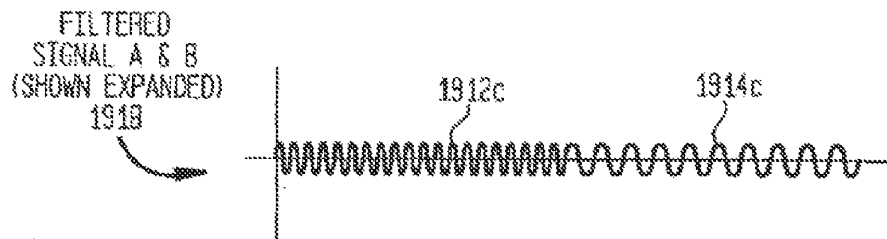


FIG. 19I

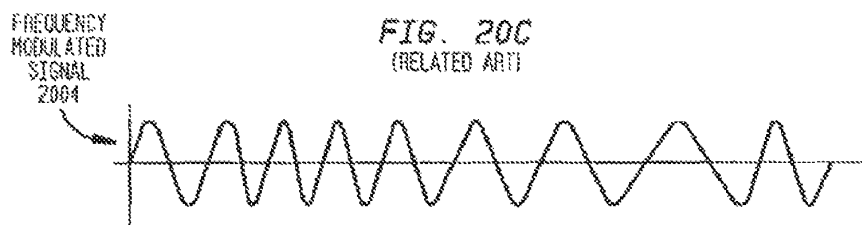
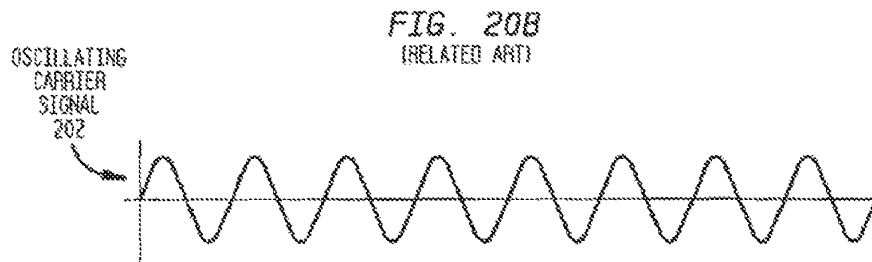
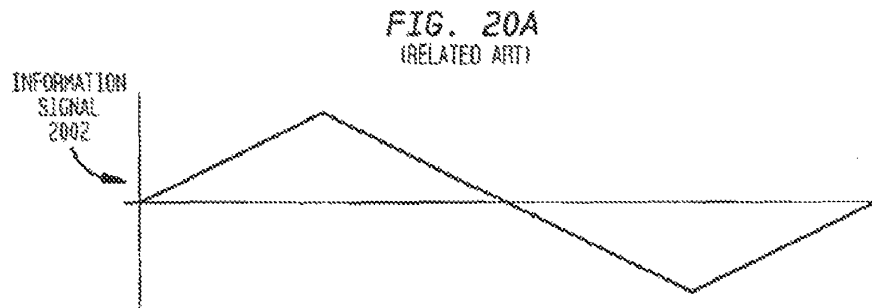


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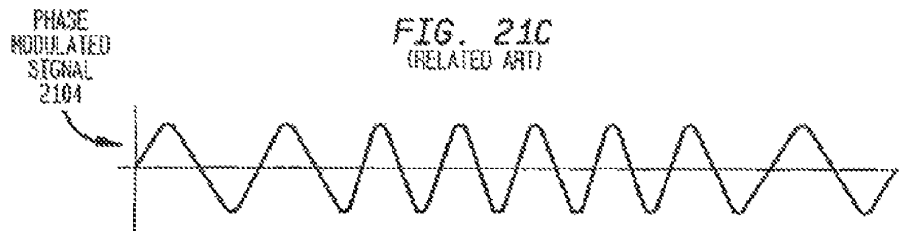
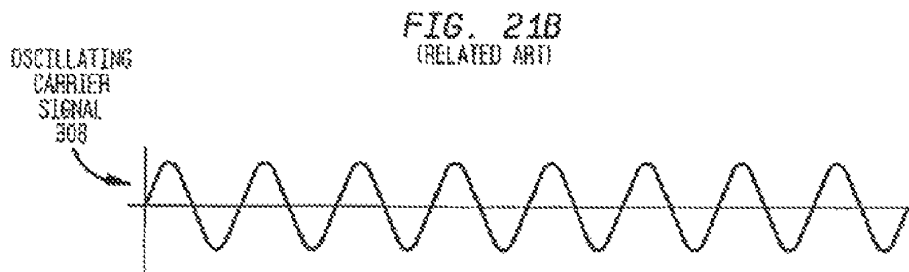
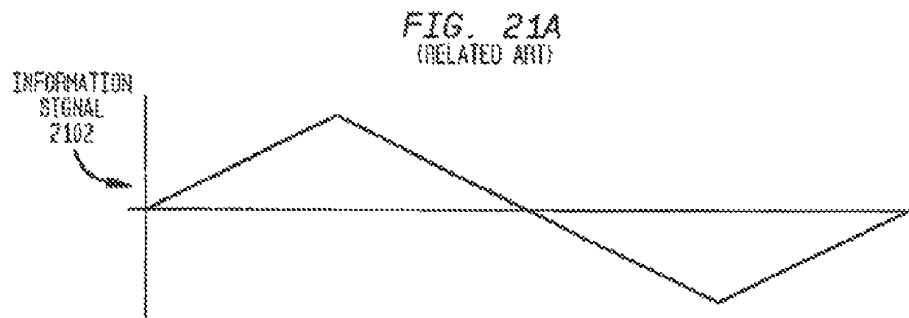


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FIG. 22A  
(RELATED ART)

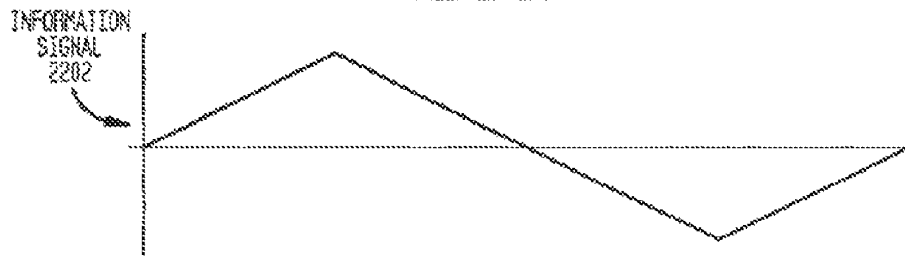


FIG. 22B  
(RELATED ART)

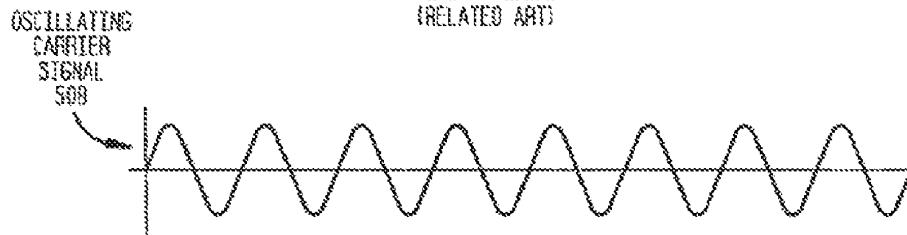


FIG. 22C  
(RELATED ART)

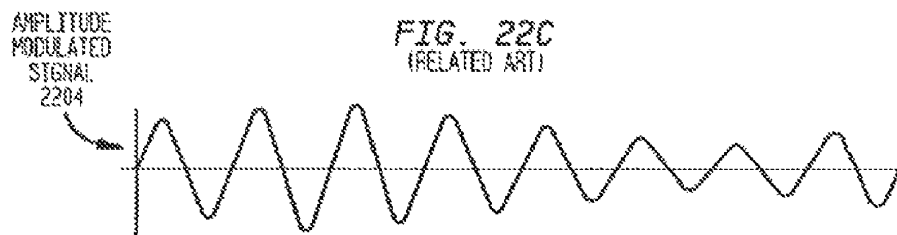
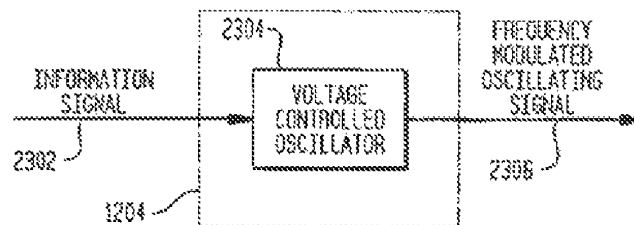


FIG. 23



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FIG. 24

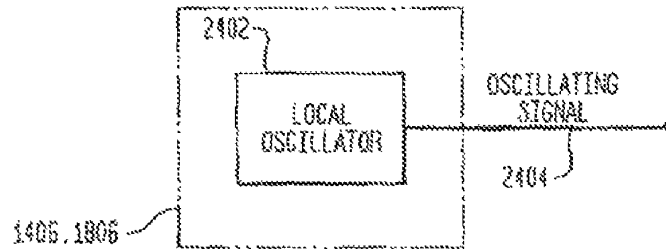


FIG. 25

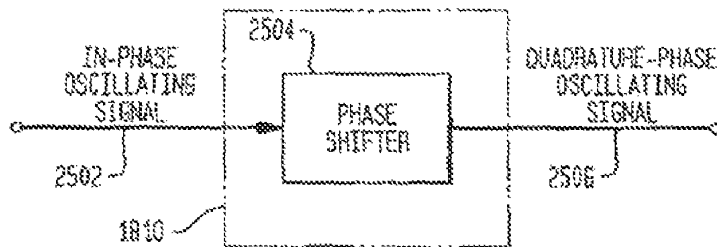


FIG. 26

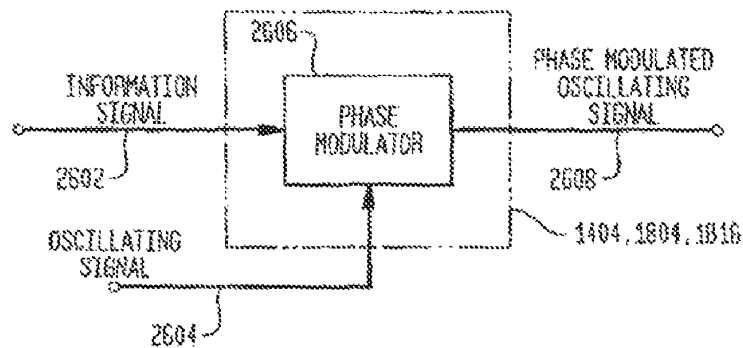
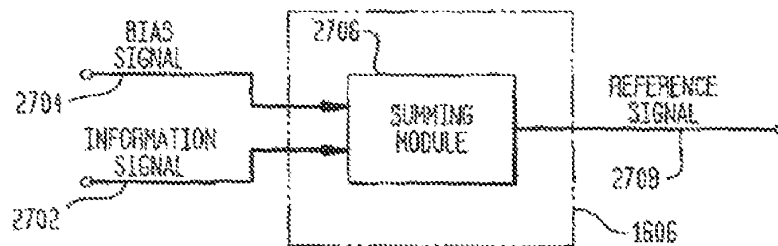


FIG. 27



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FIG. 28A

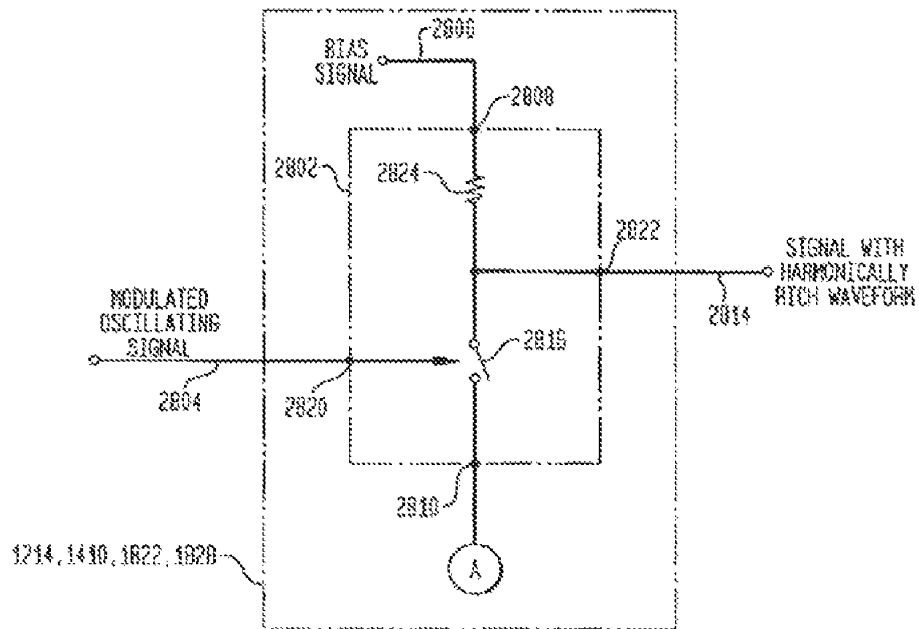
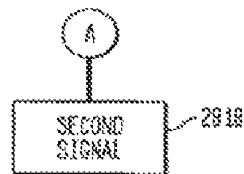


FIG. 28B



FIG. 28C



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FIG. 29A

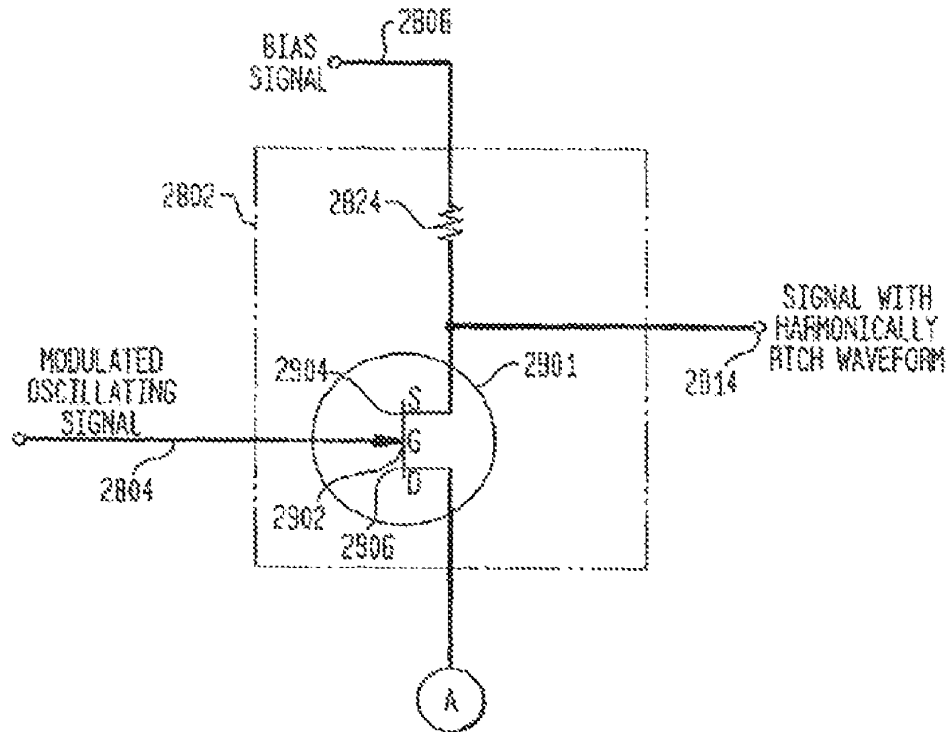
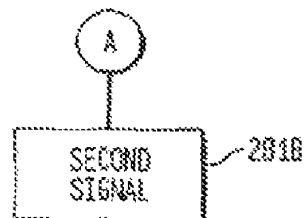


FIG. 29B



FIG. 29C



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FIG. 30A

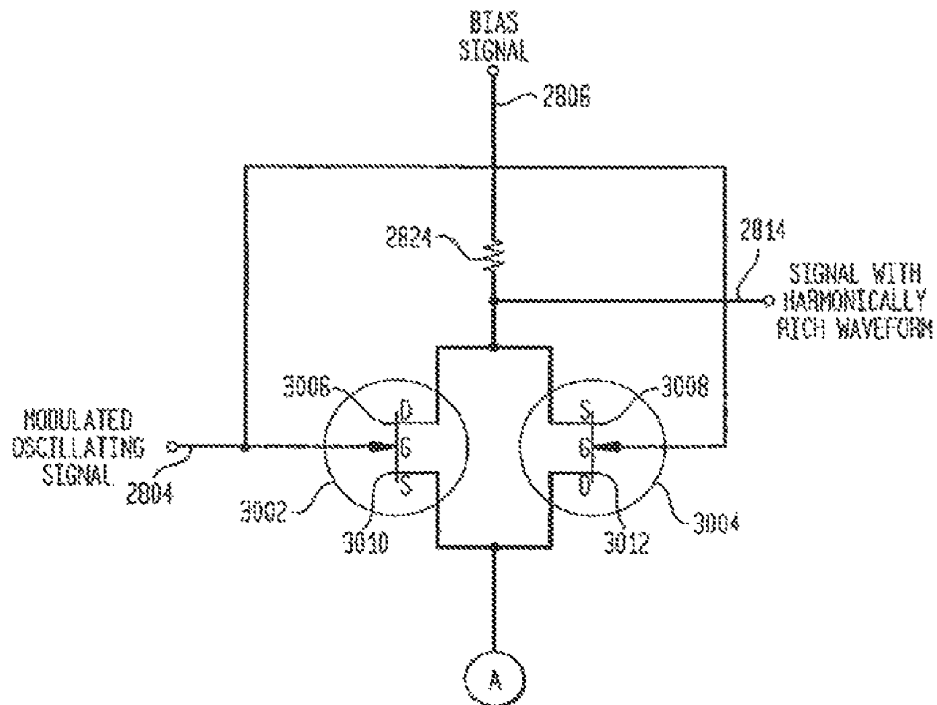
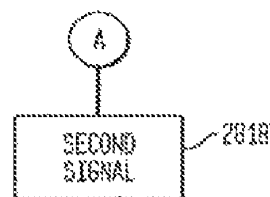


FIG. 30B



FIG. 30C



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FIG. 31A

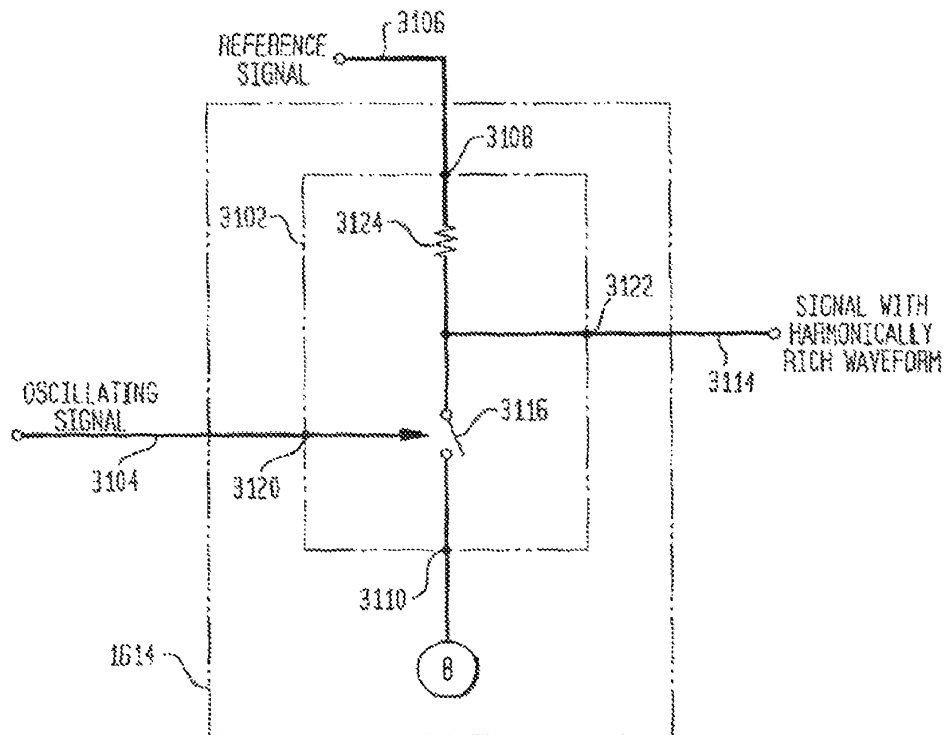


FIG. 31B

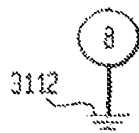
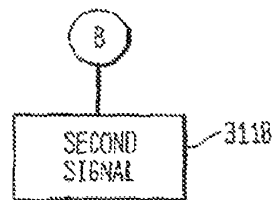


FIG. 31C



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FIG. 32A

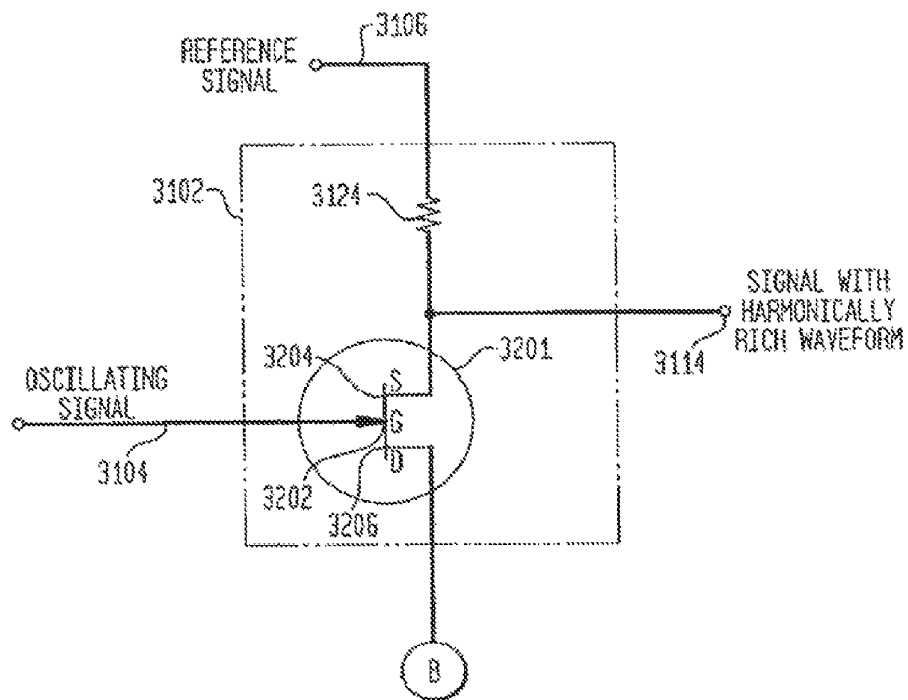


FIG. 32B

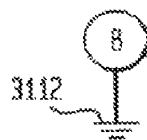
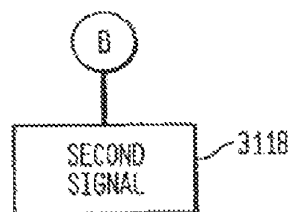


FIG. 32C

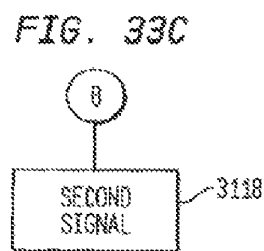
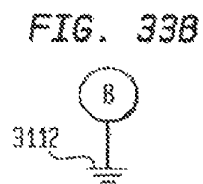
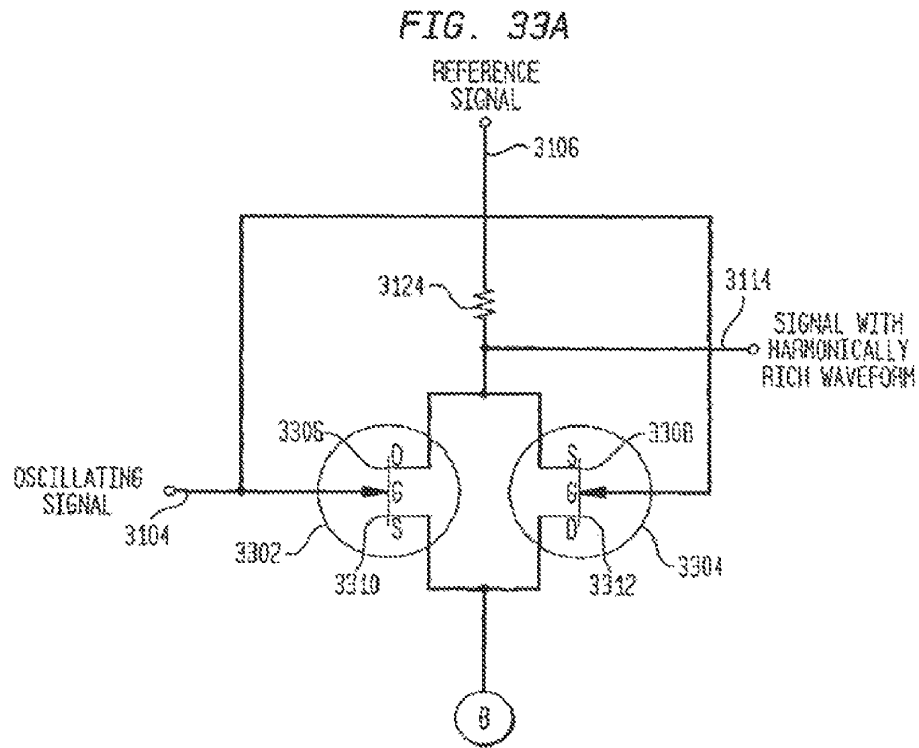


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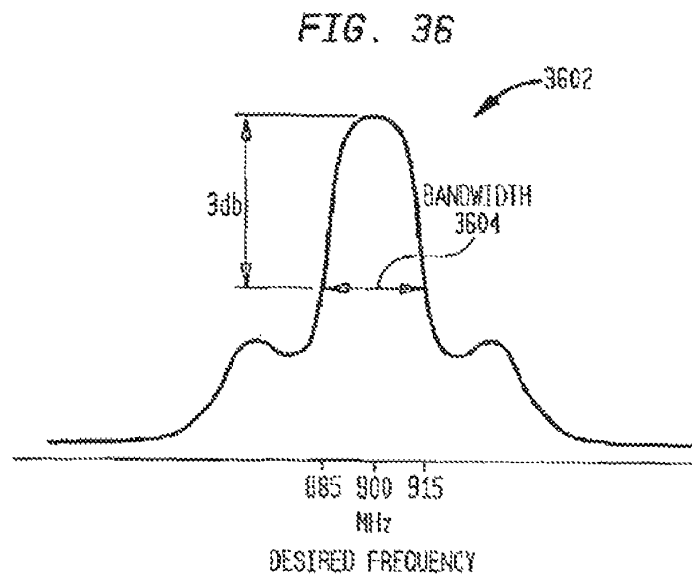
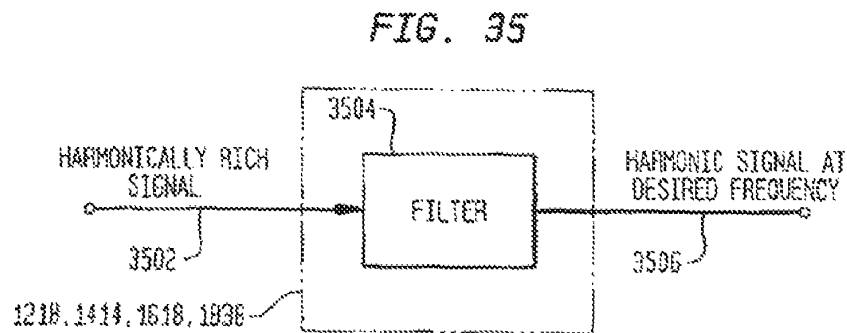
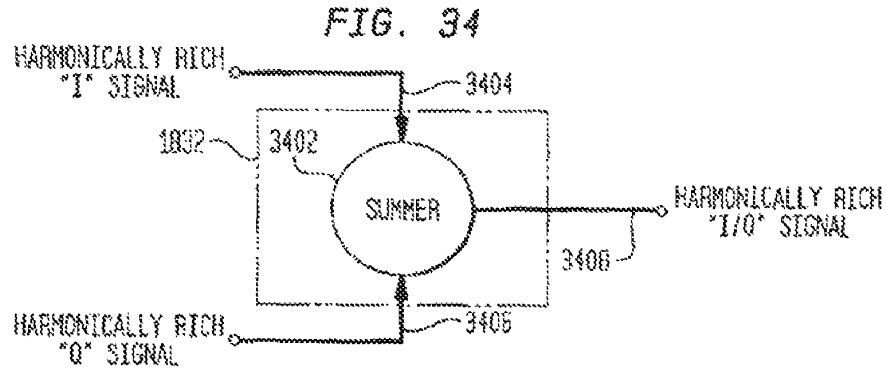


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FIG. 37A

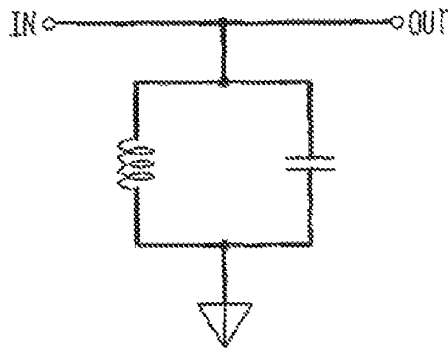


FIG. 37B

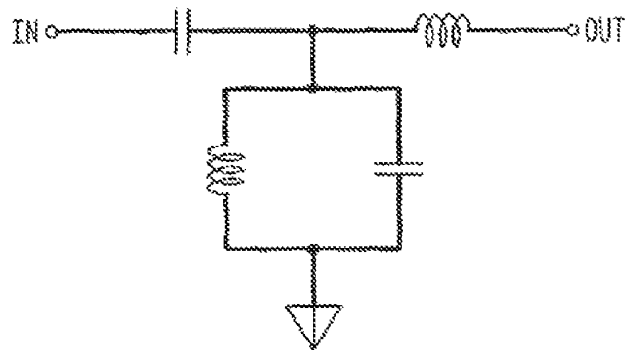
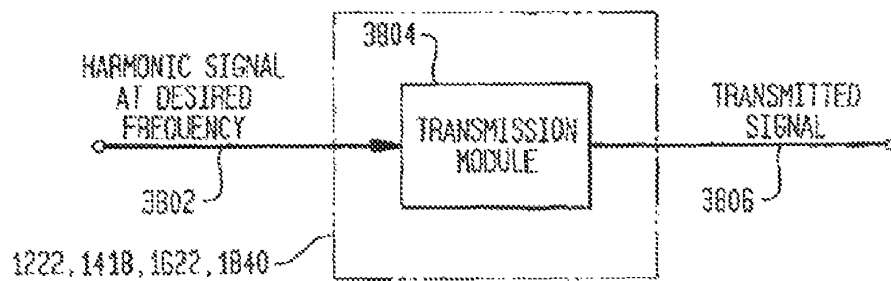


FIG. 38



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FIG. 39A

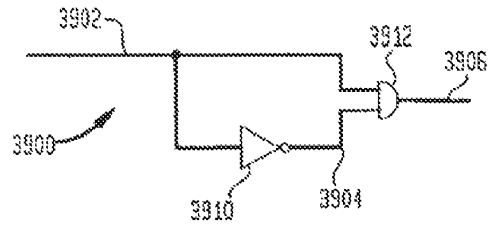


FIG. 39B

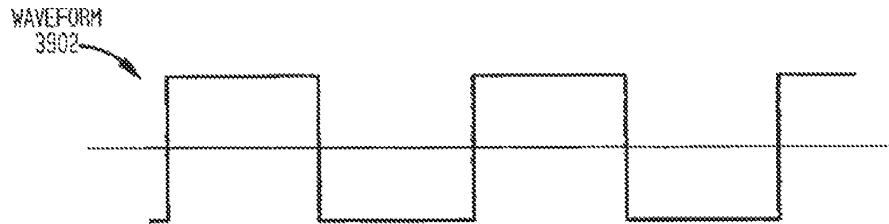


FIG. 39C

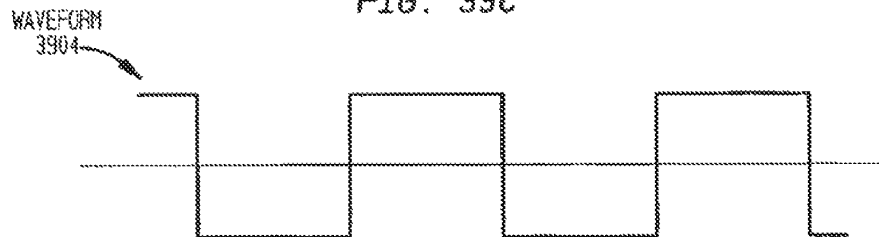
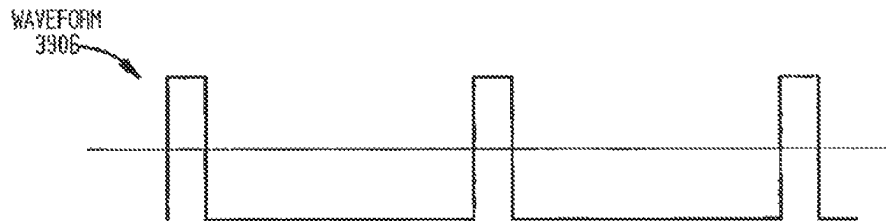


FIG. 39D



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FIG. 40A

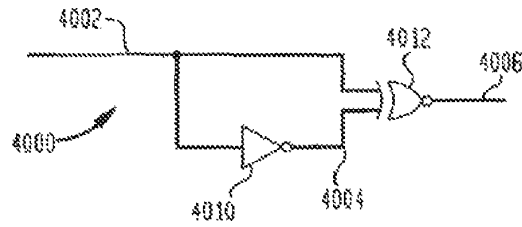


FIG. 40B

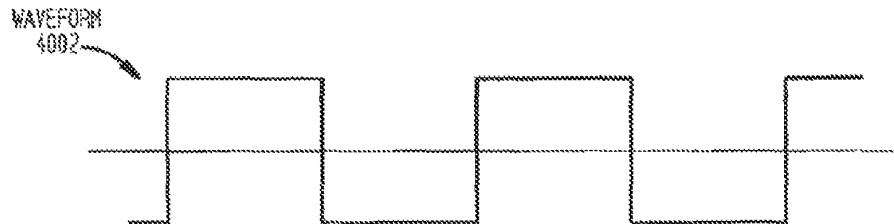


FIG. 40C

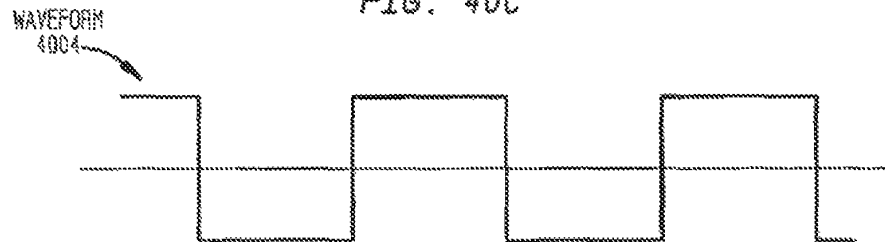
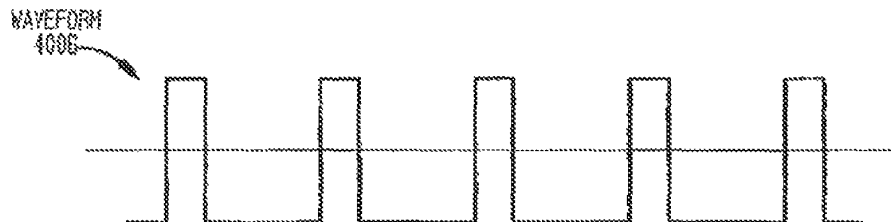


FIG. 40D



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FIG. 41

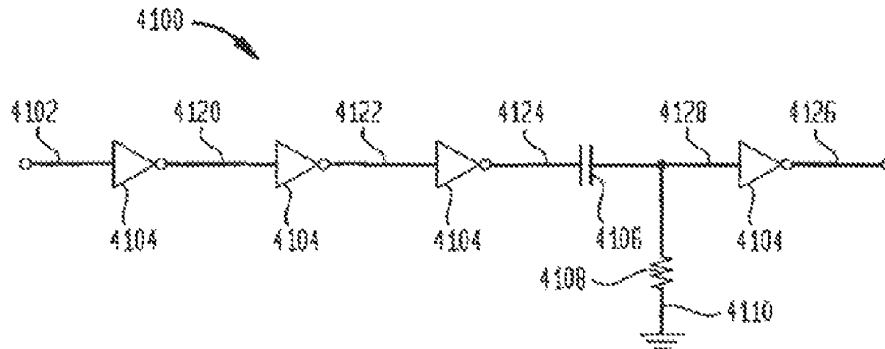


FIG. 42A

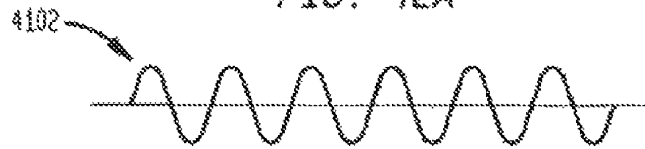


FIG. 42B

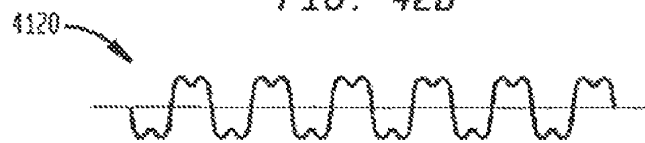


FIG. 42C

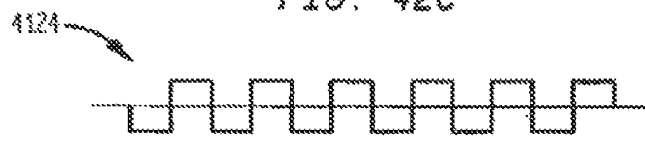


FIG. 42D

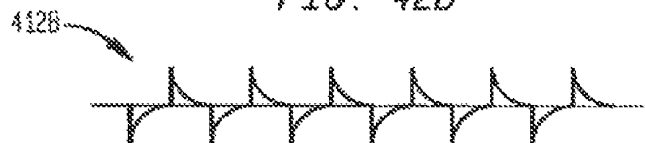


FIG. 42E



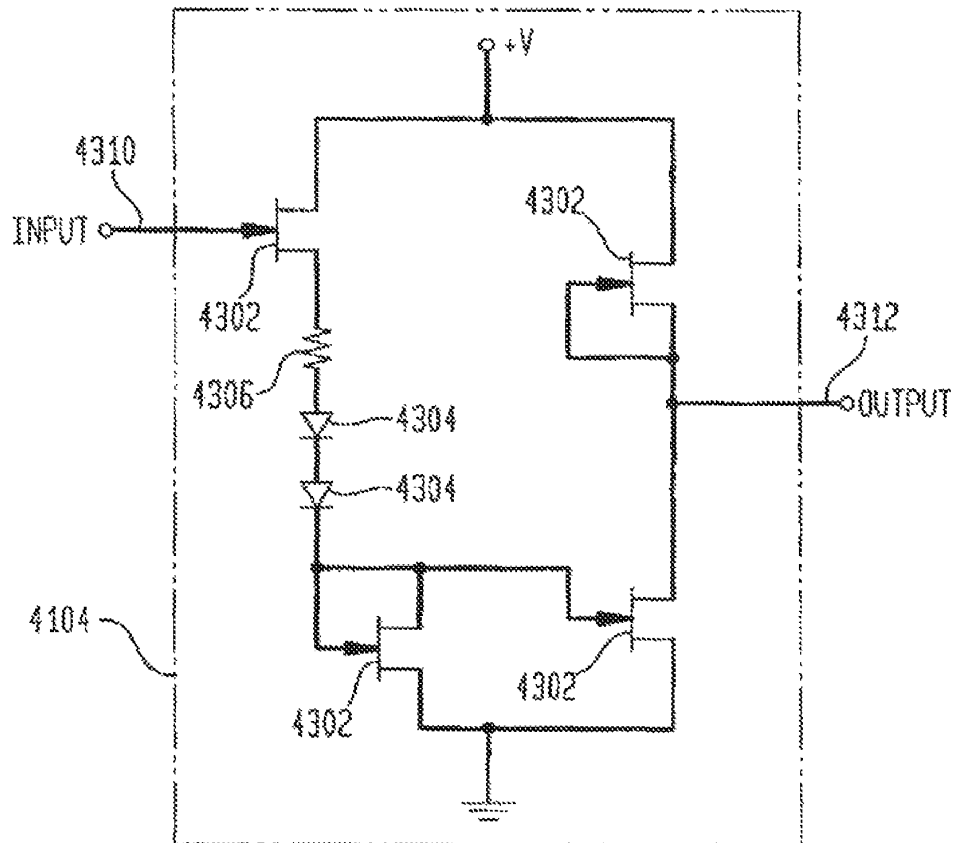
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FIG. 43

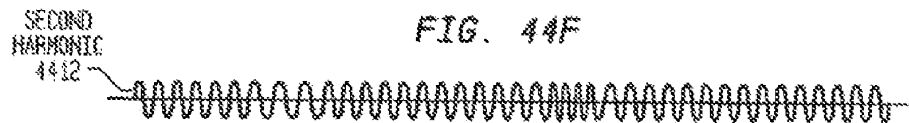
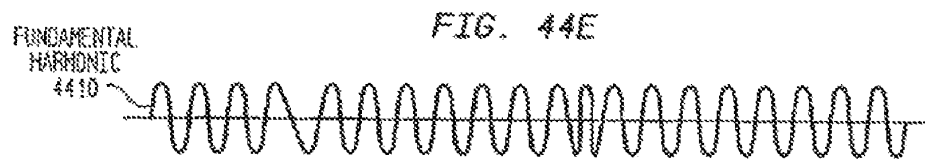
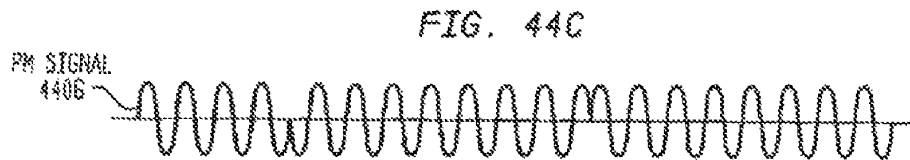
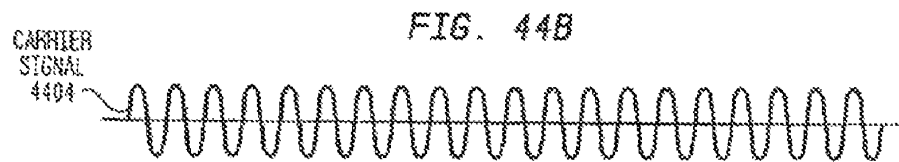
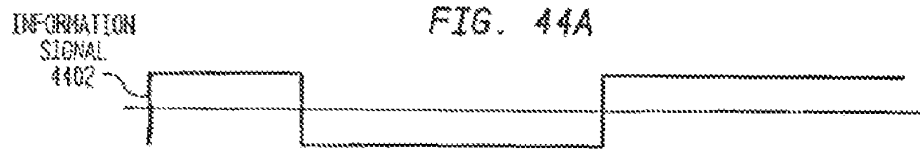


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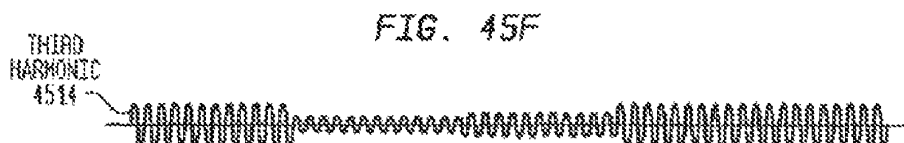
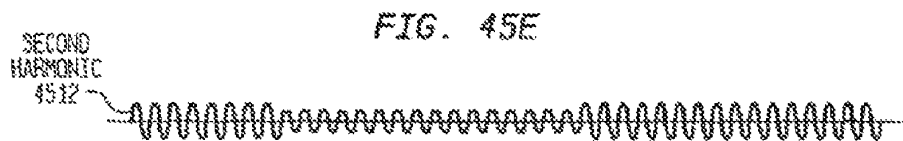
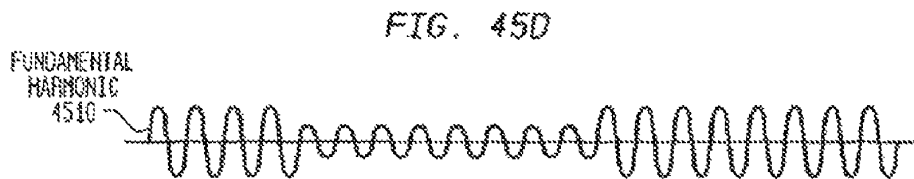
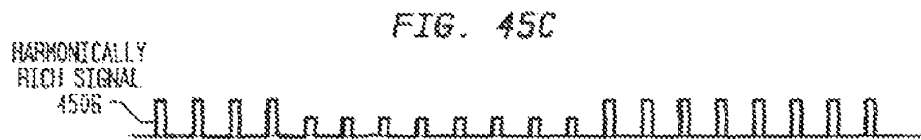
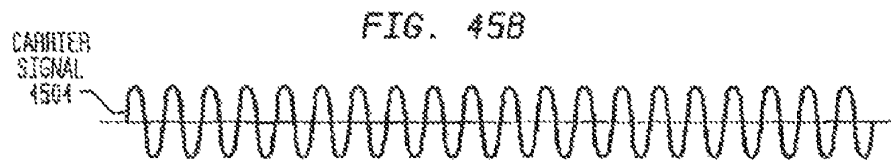
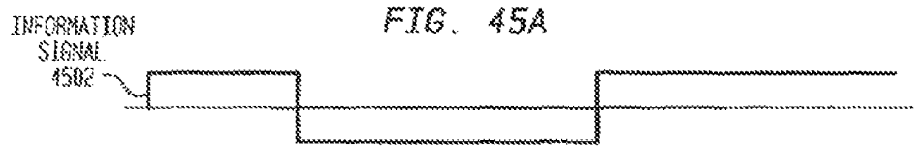


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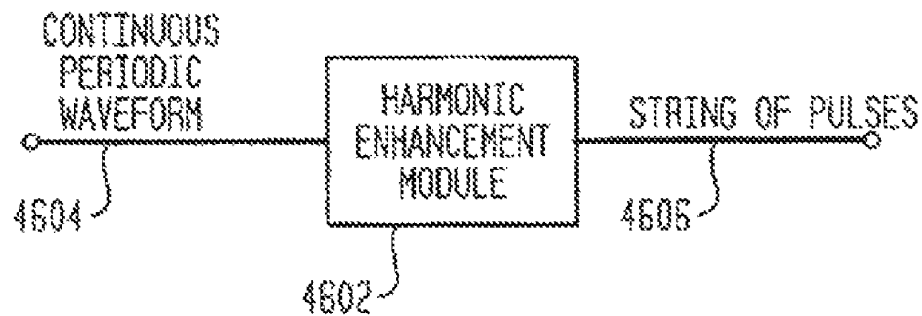
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*FIG. 46*



*FIG. 47*

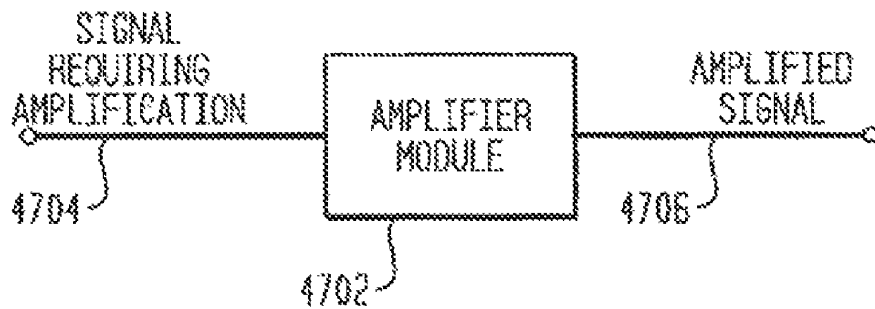


FIG. 48A

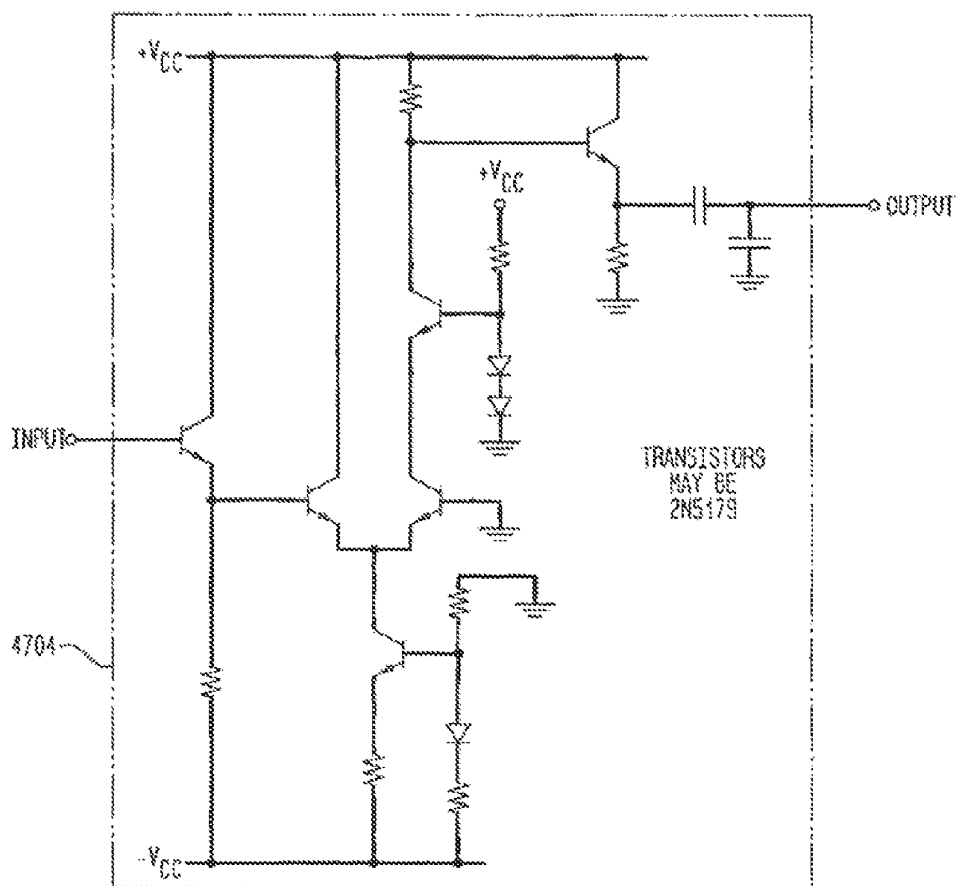


FIG. 48B

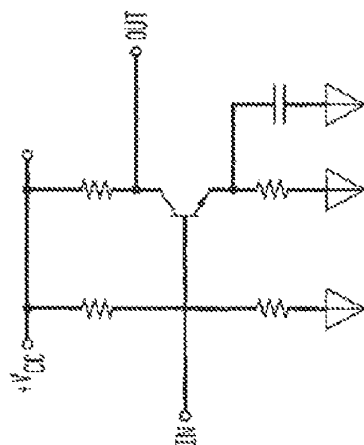
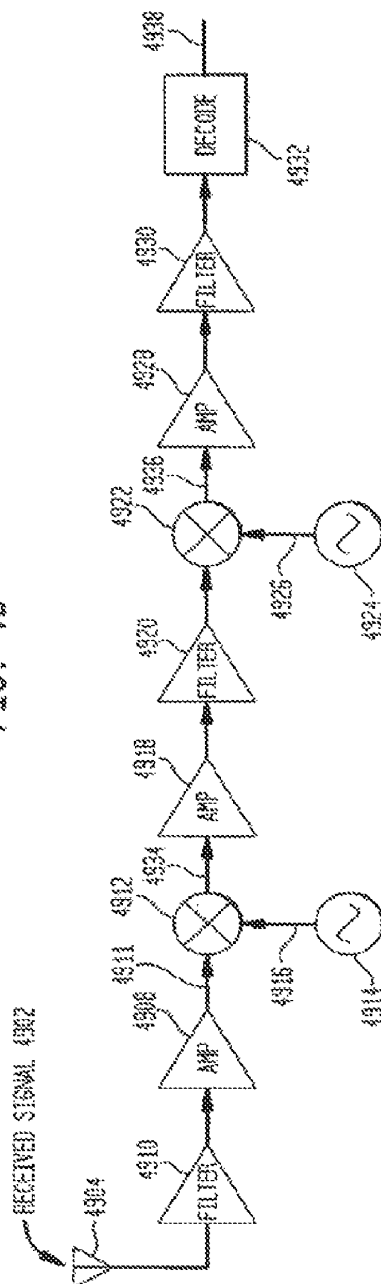


FIG. 49

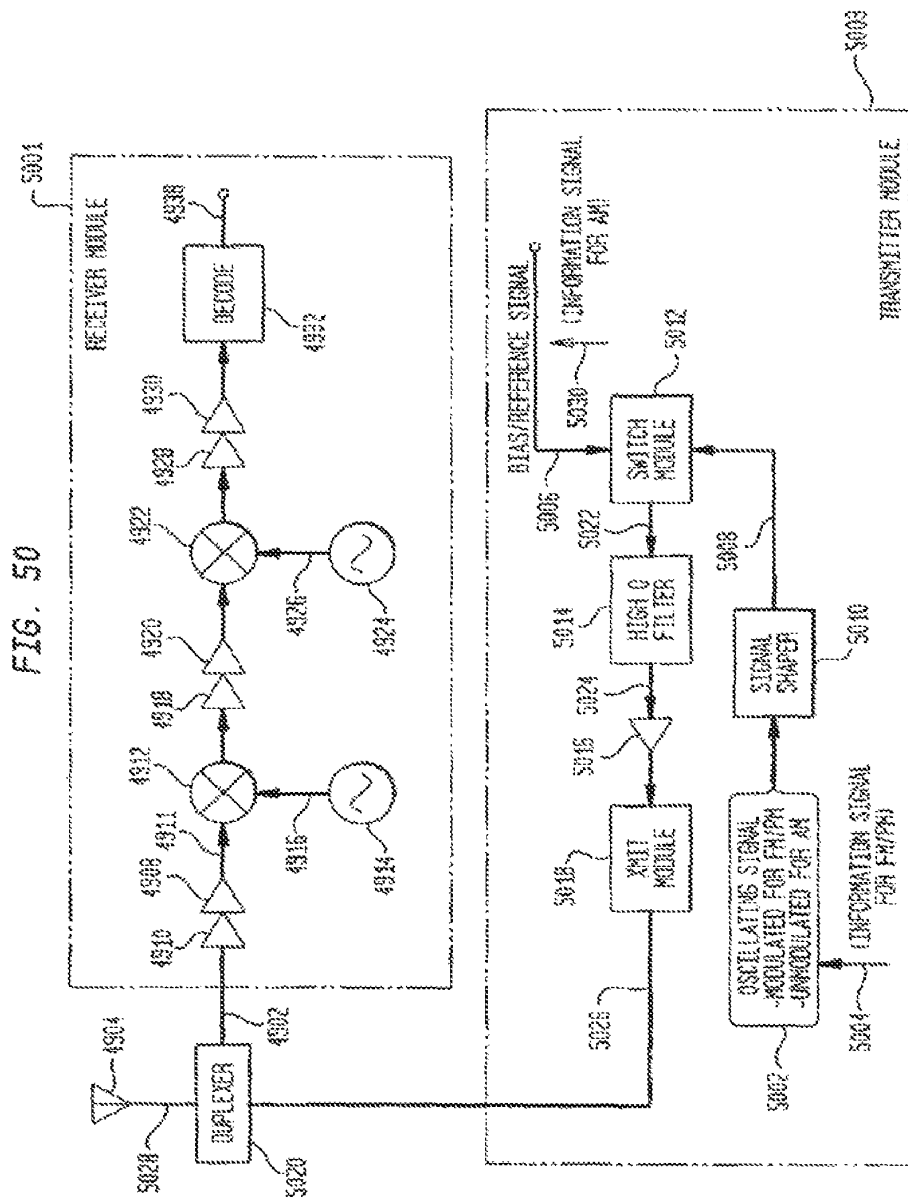


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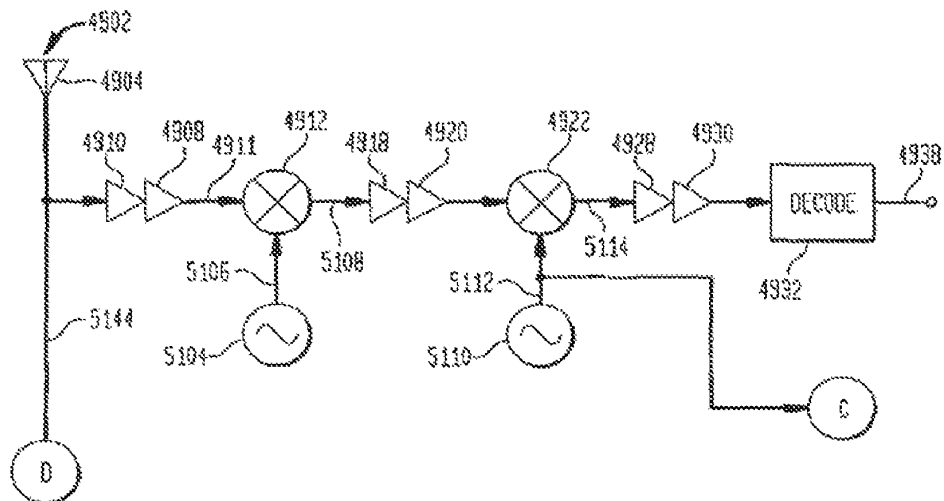
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FIG. 51A



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FIG. 51B

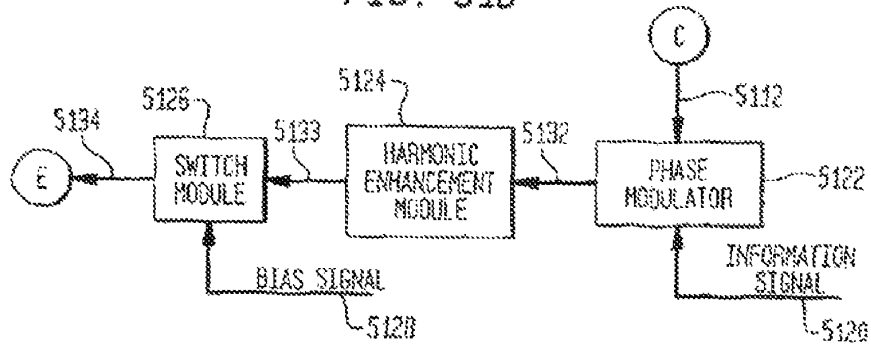


FIG. 51C

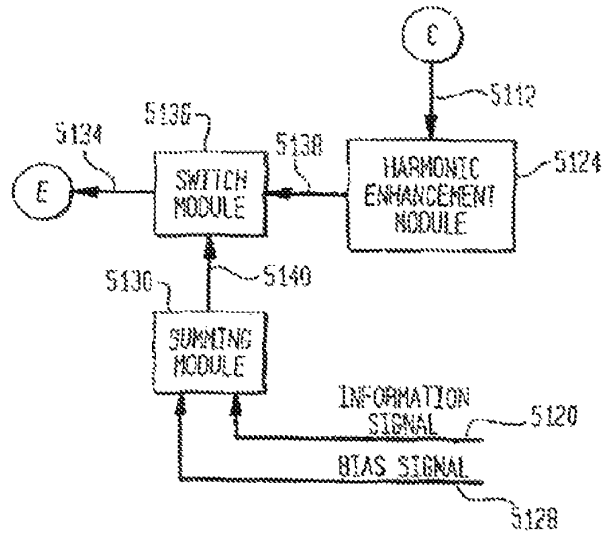
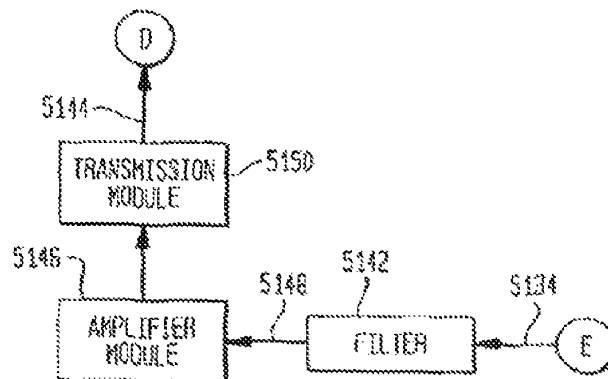


FIG. 51D



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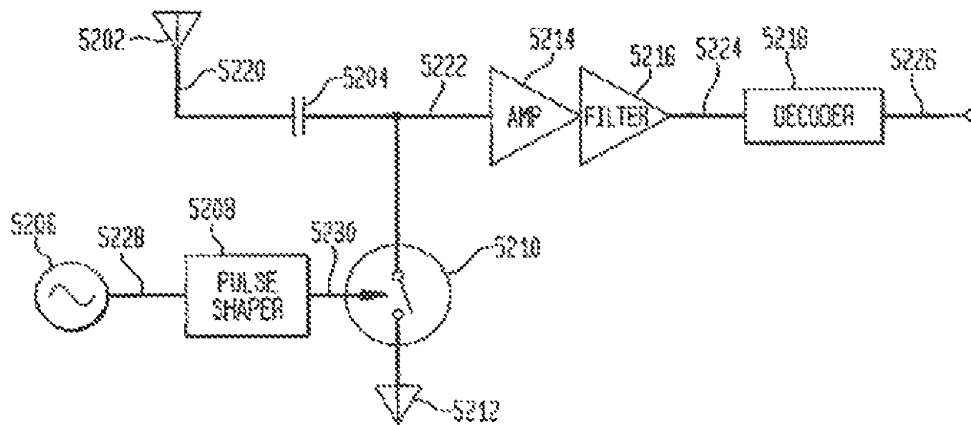
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FIG. 52

EXEMPLARY RECEIVER FOR  
UNIVERSAL FREQUENCY DOWN-CONVERSION



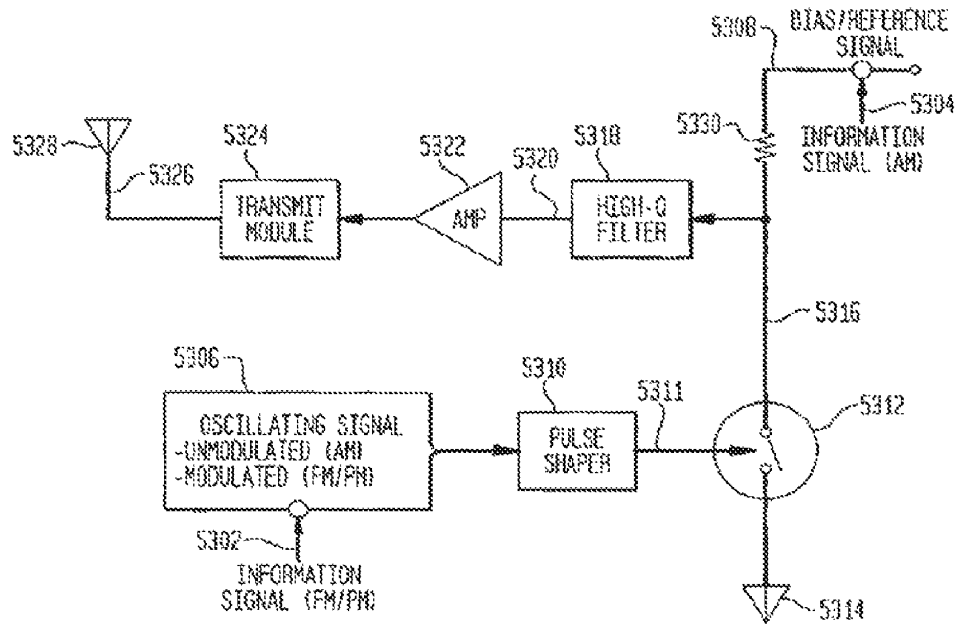
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FIG. 53

EXEMPLARY TRANSMITTER USING  
THE PRESENT INVENTION

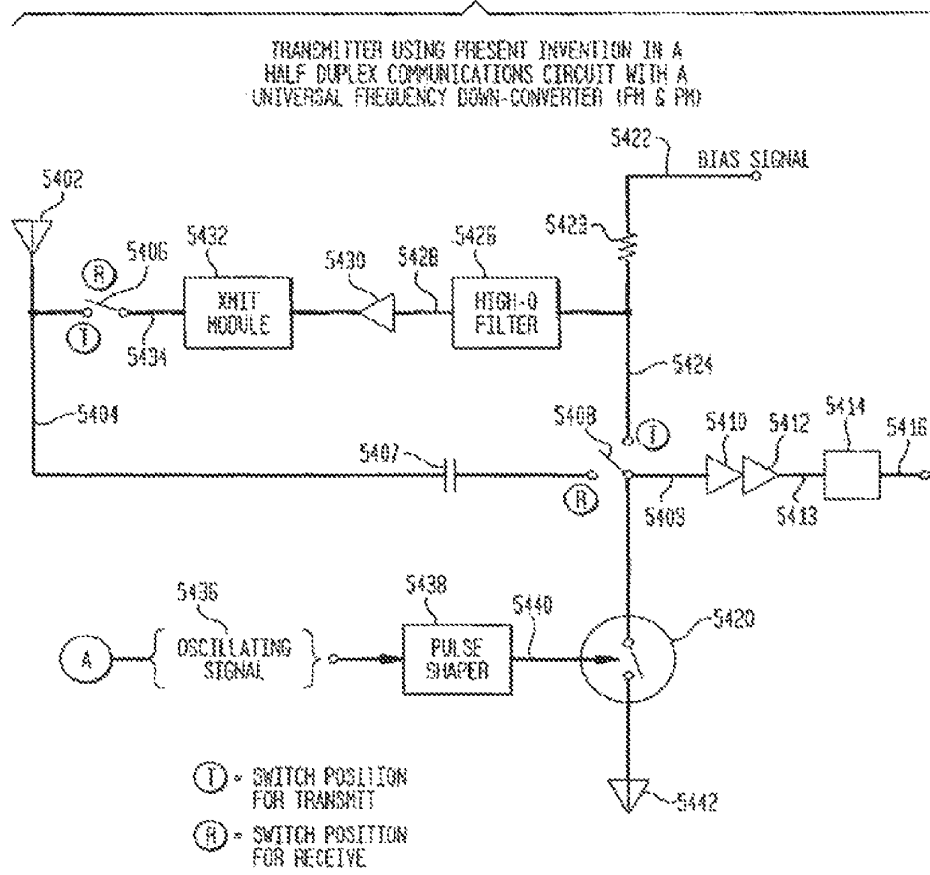
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FIG. 54A



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FIG. 54B

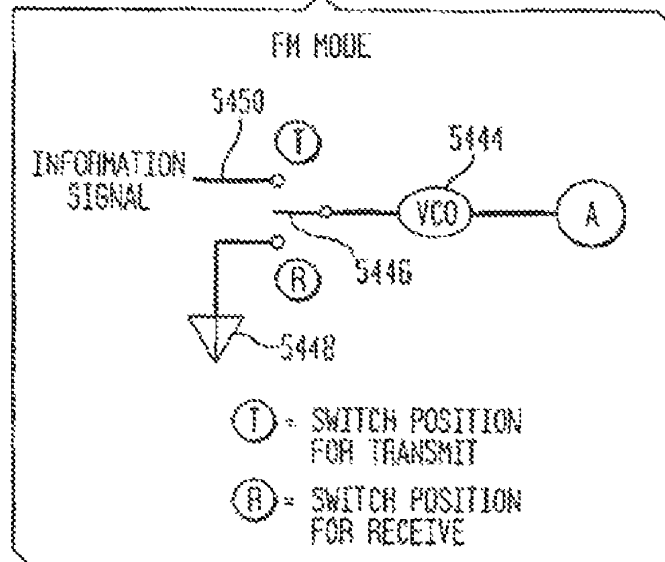
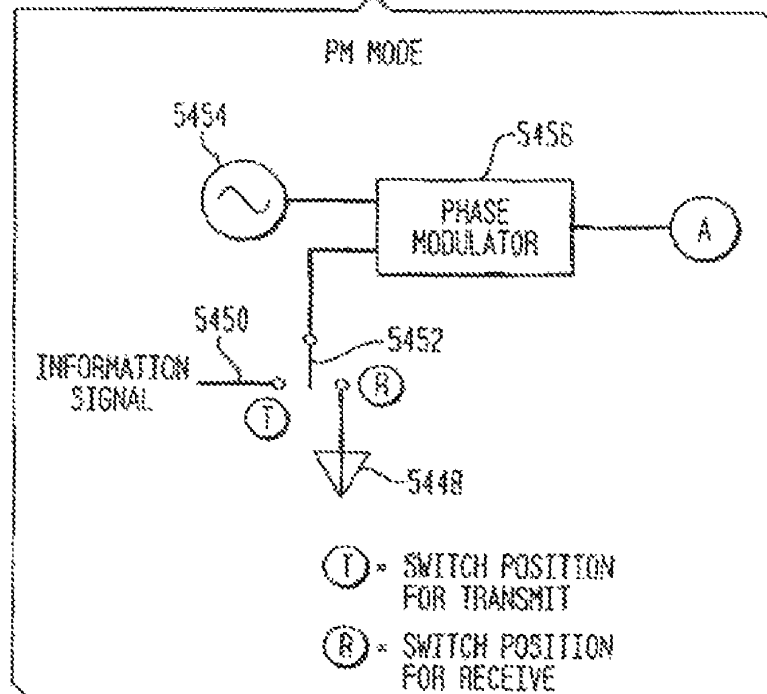


FIG. 54C



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FIG. 55

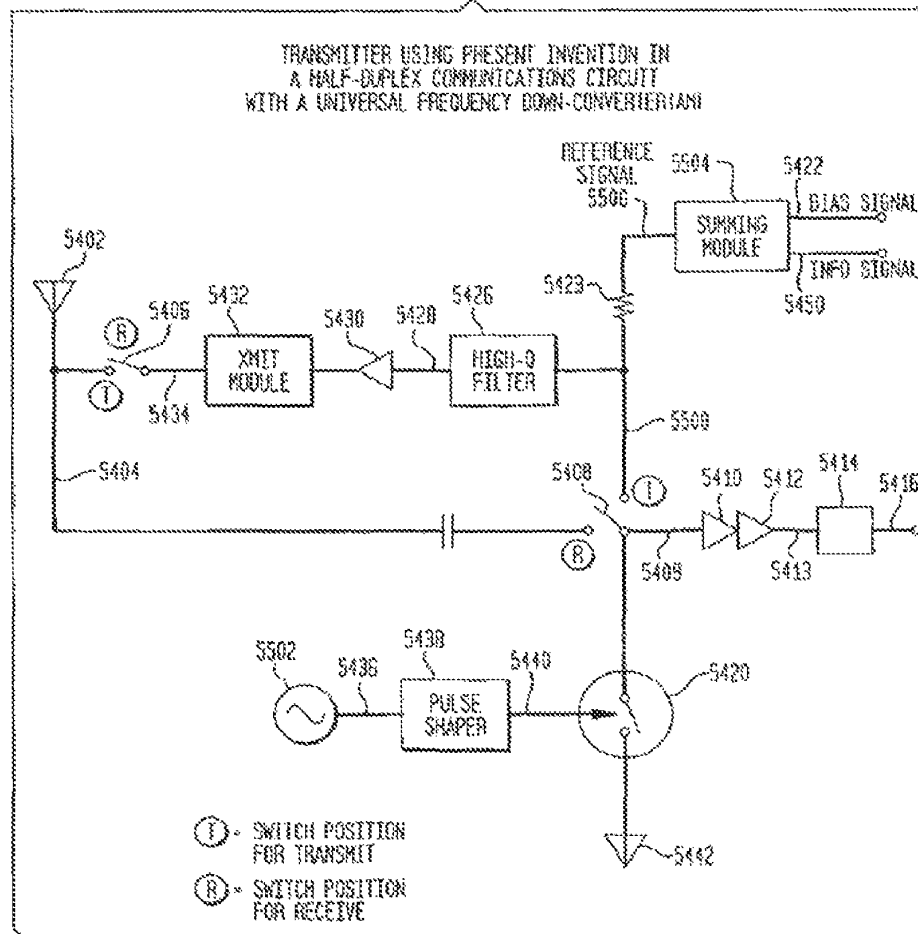
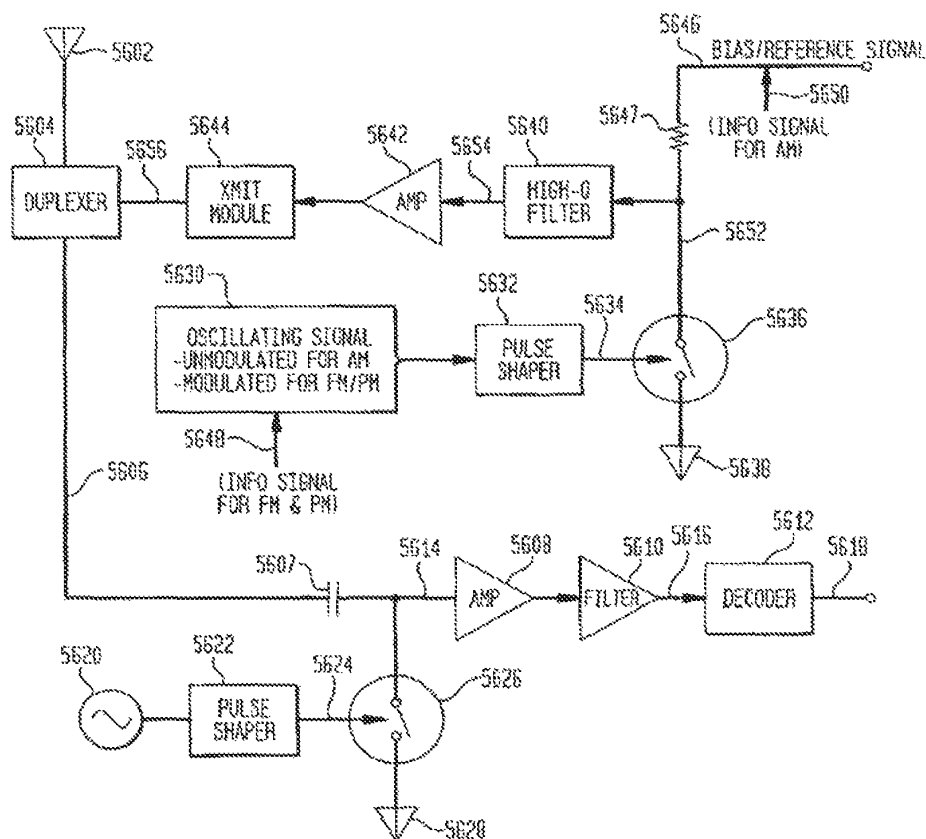


FIG. 56

TRANSMITTER USING PRESENT INVENTION IN  
FULL DUPLEX COMMUNICATIONS CIRCUIT WITH  
UNIVERSAL FREQUENCY DOWN-CONVERTER

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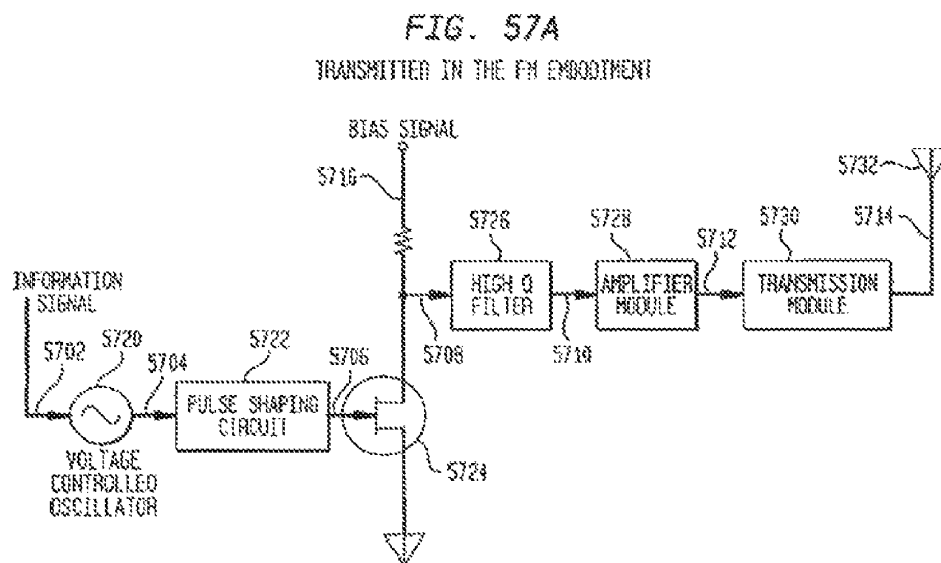


FIG. 578

TRANSMITTER IN THE FM CIRCUITMENT

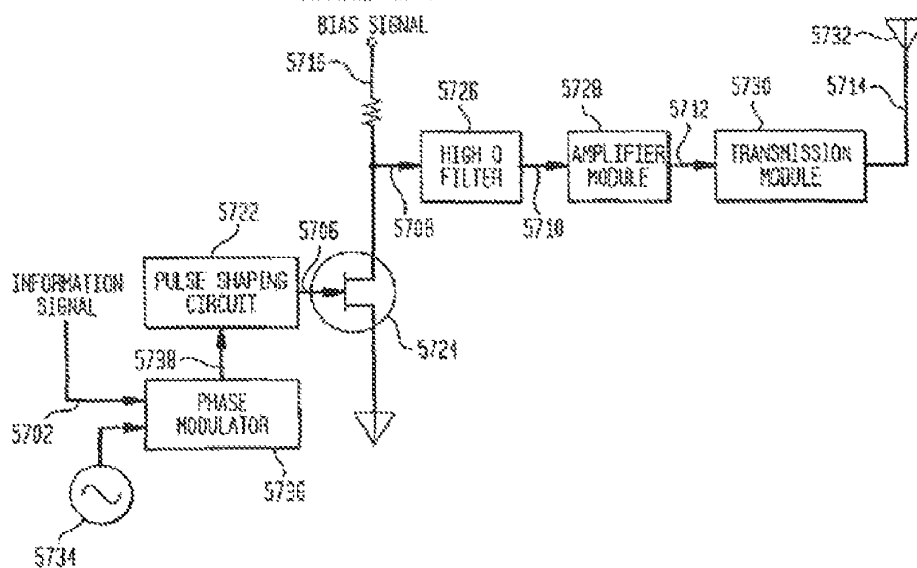
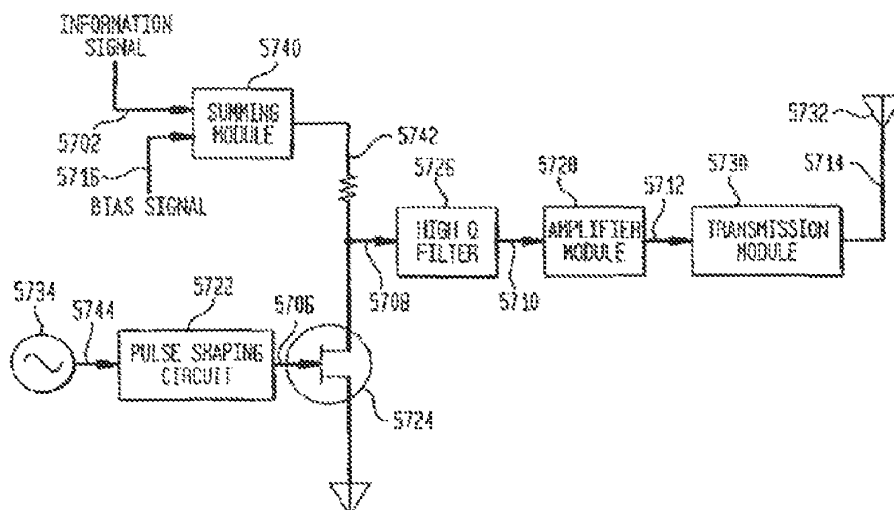


FIG. 57C

TRANSMITTER IN THE AM ENCLOSURE



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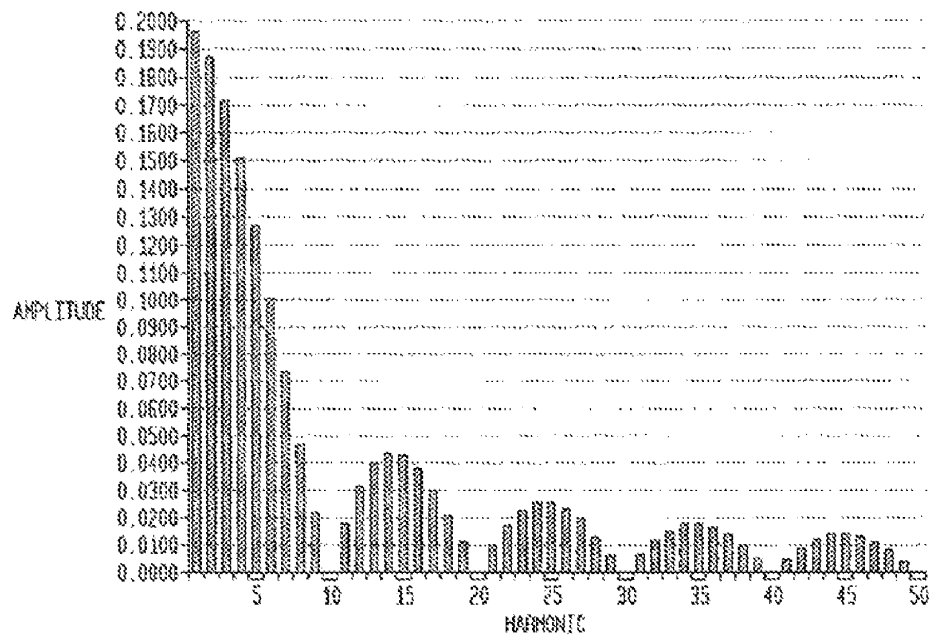
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FIG. 58

PN/T RATIO = 0.1



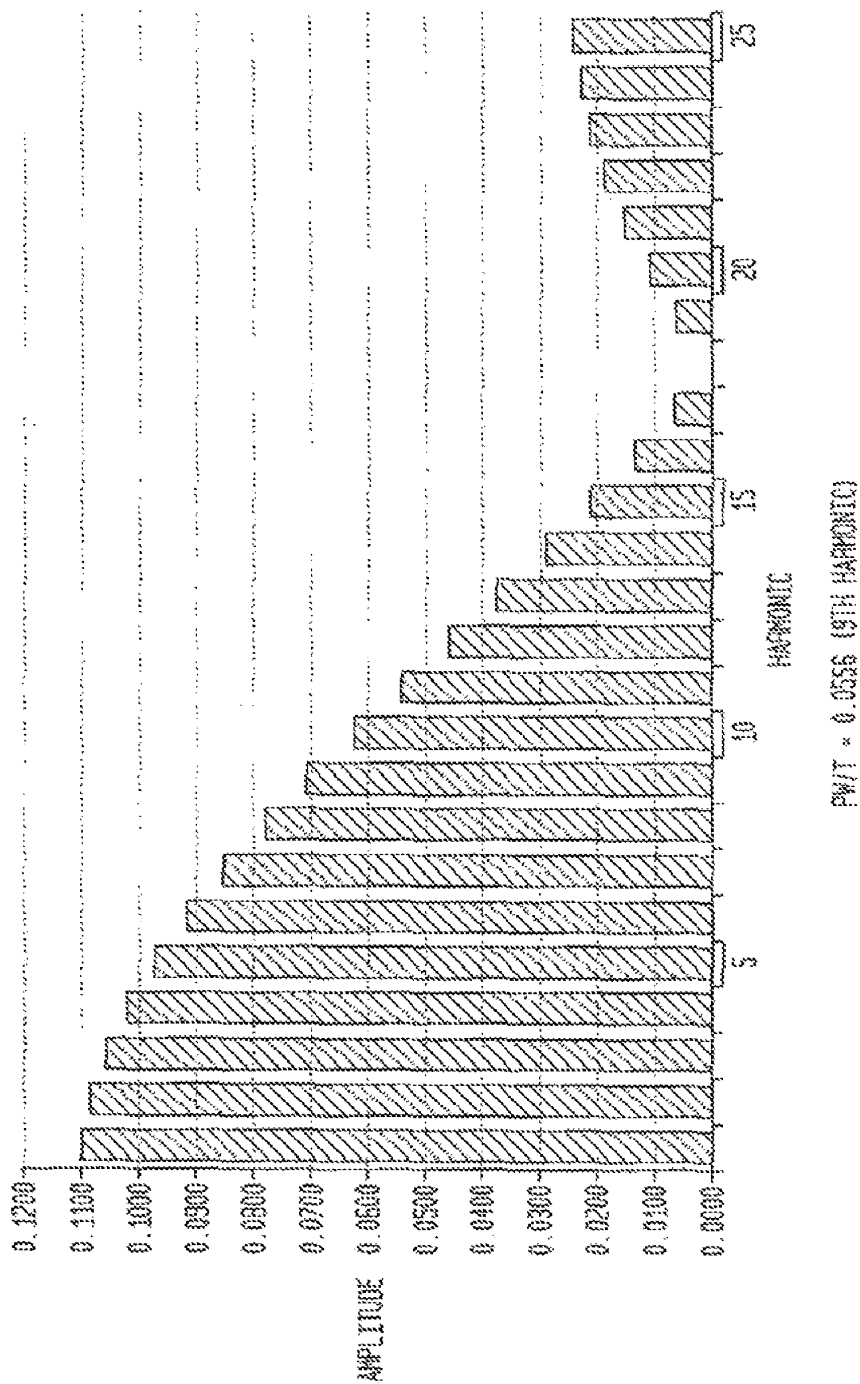
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FIG. 59



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FIG. 50

	$\pi/11$	0.500	0.250	0.100	0.050	0.010	0.005
HARMONIC							
1		0.4366	0.4502	0.1967	0.0996	0.0200	0.01000
2		0.00	0.3163	0.1971	0.0984	0.0200	0.01000
3		0.2122	0.1501	0.1717	0.0963	0.0200	0.01000
4		0.00	0.00	0.1514	0.0935	0.0199	0.00999
5		0.1273	0.0960	0.1273	0.0900	0.0199	0.00999
6		0.00	0.1051	0.1009	0.0858	0.0199	0.00999
7		0.0909	0.0649	0.0736	0.0810	0.0198	0.00998
8		0.00	0.00	0.0468	0.0757	0.0198	0.00997
9		0.0707	0.0500	0.0218	0.0699	0.0197	0.00997
10		0.00	0.0637	0.00	0.0637	0.0197	0.00996
11		0.0579	0.0409	0.0179	0.0572	0.0196	0.00995
12		0.00	0.00	0.0312	0.0505	0.0195	0.00994
13		0.0490	0.0346	0.0390	0.0436	0.0194	0.00993
14		0.00	0.0455	0.0432	0.0368	0.0194	0.00992
15		0.0424	0.0300	0.0424	0.0300	0.0193	0.00991
16		0.00	0.00	0.0378	0.0234	0.0192	0.00990
17		0.0374	0.0265	0.0303	0.0170	0.0191	0.00988
18		0.00	0.0154	0.0208	0.0109	0.0190	0.00987
19		0.0335	0.0217	0.0104	0.0052	0.0188	0.00985
20		0.00	0.00	0.00	0.00	0.0187	0.00984
21		0.0309	0.0214	0.0094	0.0047	0.0186	0.00982
22		0.00	0.0293	0.0170	0.0093	0.0184	0.00980
23		0.0277	0.0196	0.0224	0.0126	0.0183	0.00978
24		0.00	0.00	0.0252	0.0156	0.0182	0.00976
25		0.0255	0.0180	0.0255	0.0160	0.0180	0.00974
26		0.00	0.0245	0.0233	0.0199	0.0178	0.00972
27		0.0236	0.0167	0.0191	0.0210	0.0177	0.00970
28		0.00	0.00	0.0134	0.0215	0.0175	0.00968
29		0.0220	0.0155	0.0080	0.0217	0.0173	0.00966
30		0.00	0.0212	0.00	0.0212	0.0172	0.00963
31		0.0205	0.0145	0.0063	0.0203	0.0170	0.00961
32		0.00	0.00	0.0117	0.0199	0.0168	0.00958
33		0.0193	0.0136	0.0156	0.0172	0.0166	0.00956
34		0.00	0.0187	0.0178	0.0151	0.0164	0.00953
35		0.0182	0.0129	0.0182	0.0129	0.0162	0.00950
36		0.00	0.00	0.0168	0.0164	0.0160	0.00948
37		0.0172	0.0122	0.0139	0.0078	0.0159	0.00945
38		0.00	0.0160	0.0090	0.0052	0.0156	0.00942
39		0.0163	0.0115	0.0050	0.0026	0.0154	0.00939
40		0.00	0.00	0.00	0.00	0.0151	0.00935
41		0.0155	0.0110	0.0046	0.0024	0.0149	0.00932
42		0.00	0.0152	0.0089	0.0047	0.0147	0.00929
43		0.0148	0.0105	0.0120	0.0067	0.0144	0.00926
44		0.00	0.00	0.0136	0.0085	0.0142	0.00922
45		0.0141	0.0100	0.0141	0.0100	0.0140	0.00918
46		0.00	0.0138	0.0132	0.0112	0.0137	0.00915
47		0.0135	0.0096	0.0110	0.0121	0.0135	0.00912
48		0.00	0.00	0.0078	0.0126	0.0132	0.00908
49		0.0130	0.0092	0.0048	0.0128	0.0130	0.00904
50		0.00	0.0127	0.00	0.0127	0.0127	0.00900

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FIG. 61

8100

HARMONIC	T/1	1	2	3	4	5	6	7	8	9	10
1	0.5000	0.2500	0.1667	0.1250	0.1000	0.0833	0.0714	0.0625	0.0556	0.0500	0.0500
2	0.6356	0.4502	0.3183	0.2436	0.1967	0.1646	0.1417	0.1242	0.1105	0.0996	0.0996
3	0.0000	0.3183	0.2757	0.2251	0.1871	0.1582	0.1381	0.1218	0.1083	0.0984	0.0984
4	0.2122	0.1501	0.2122	0.1581	0.1171	0.0901	0.0773	0.0683	0.0613	0.0563	0.0563
5	0.0000	0.0000	0.1379	0.1582	0.1514	0.1370	0.1244	0.1125	0.1023	0.0935	0.0935
6	0.1273	0.0300	0.0637	0.1176	0.1273	0.1220	0.1147	0.1059	0.0973	0.0900	0.0900
7	0.0000	0.1061	0.0000	0.0750	0.1009	0.1061	0.1034	0.0980	0.0919	0.0858	0.0858
8	0.0308	0.0543	0.0455	0.0348	0.0736	0.0878	0.0909	0.0932	0.0955	0.0980	0.0980
9	0.0000	0.0000	0.0689	0.0000	0.0468	0.0689	0.0776	0.0796	0.0841	0.0874	0.0874
10	0.0707	0.0500	0.0707	0.0271	0.0219	0.0500	0.0537	0.0554	0.0571	0.0588	0.0588
11	0.0000	0.0537	0.0553	0.0450	0.0000	0.0318	0.0498	0.0588	0.0627	0.0657	0.0657
12	0.0579	0.0408	0.0282	0.0535	0.0179	0.0150	0.0261	0.0281	0.0294	0.0305	0.0305
13	0.0000	0.0000	0.0000	0.0511	0.0312	0.0000	0.0230	0.0275	0.0359	0.0505	0.0505
14	0.0490	0.0346	0.0245	0.0452	0.0336	0.0127	0.0199	0.0272	0.0375	0.0436	0.0436
15	0.0000	0.0455	0.0394	0.0322	0.0432	0.0227	0.0000	0.0174	0.0292	0.0368	0.0368
16	0.0424	0.0300	0.0424	0.0382	0.0424	0.0300	0.0094	0.0093	0.0212	0.0300	0.0300
17	0.0000	0.0000	0.0345	0.0000	0.0378	0.0345	0.0173	0.0000	0.0136	0.0234	0.0234
18	0.0374	0.0265	0.0187	0.0343	0.0303	0.0362	0.0233	0.0073	0.0053	0.0170	0.0170
19	0.0000	0.0354	0.0000	0.0250	0.0298	0.0354	0.0277	0.0335	0.0200	0.0103	0.0103
20	0.0335	0.0237	0.0168	0.0310	0.0104	0.0324	0.0302	0.0486	0.0050	0.0052	0.0052
21	0.0000	0.0000	0.0278	0.0318	0.0000	0.0276	0.0310	0.0225	0.0109	0.0000	0.0000
22	0.0303	0.0214	0.0303	0.0200	0.0354	0.0214	0.0303	0.0252	0.0152	0.0017	0.0017
23	0.0000	0.0289	0.0251	0.0205	0.0170	0.0145	0.0282	0.0267	0.0186	0.0069	0.0069
24	0.0277	0.0155	0.0138	0.0105	0.0224	0.0072	0.0249	0.0271	0.0212	0.0126	0.0126
25	0.0000	0.0000	0.0000	0.0000	0.0252	0.0000	0.0207	0.0265	0.0230	0.0156	0.0156
26	0.0255	0.0160	0.0127	0.0057	0.0255	0.0056	0.0159	0.0250	0.0239	0.0180	0.0180

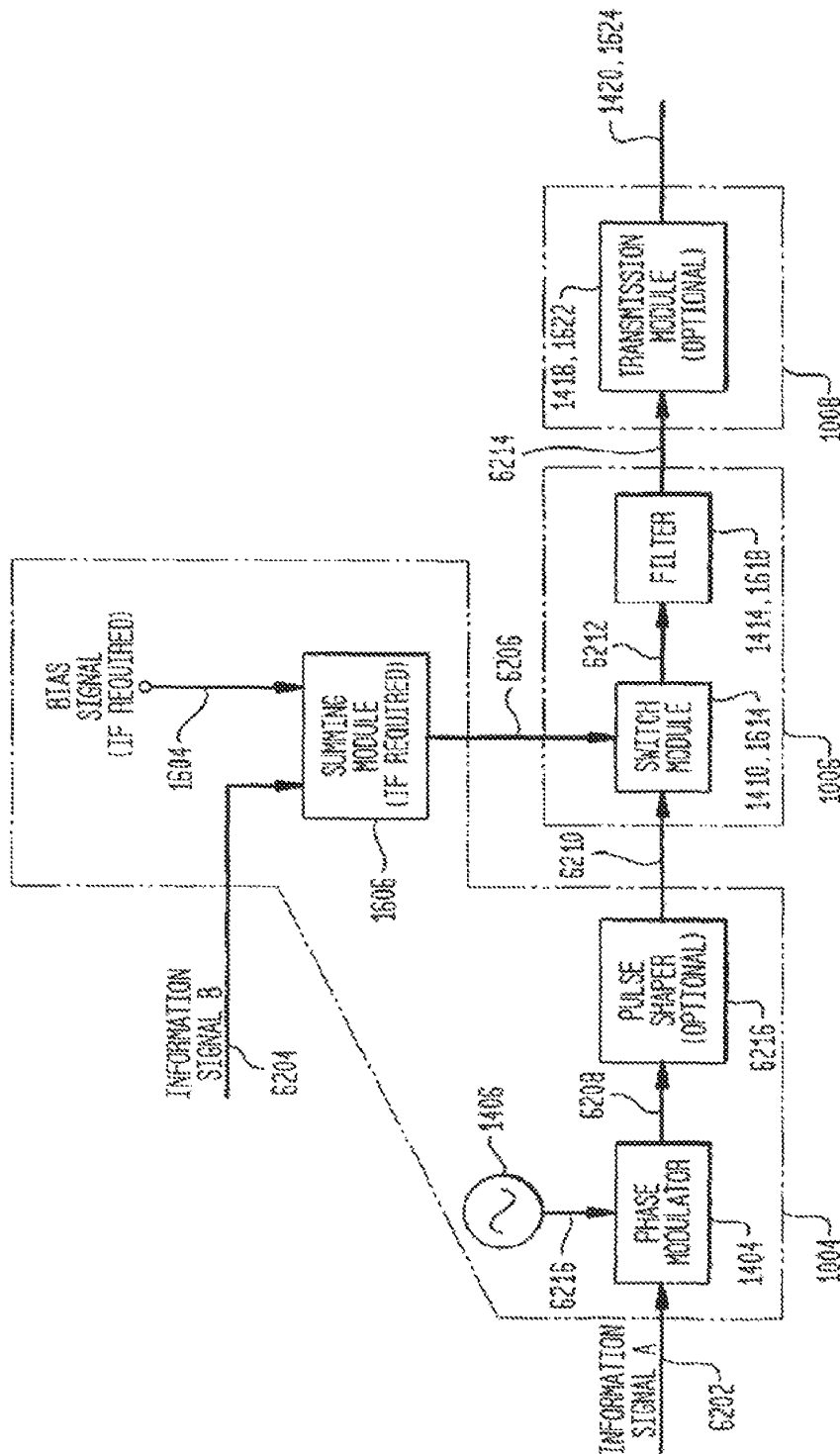
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FIG. 62

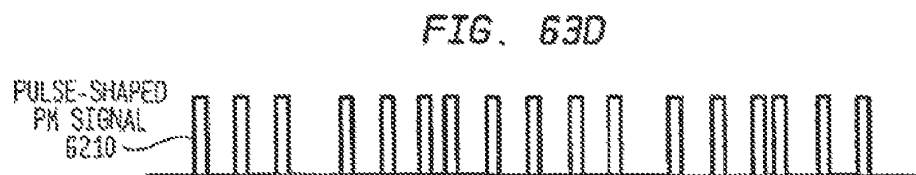
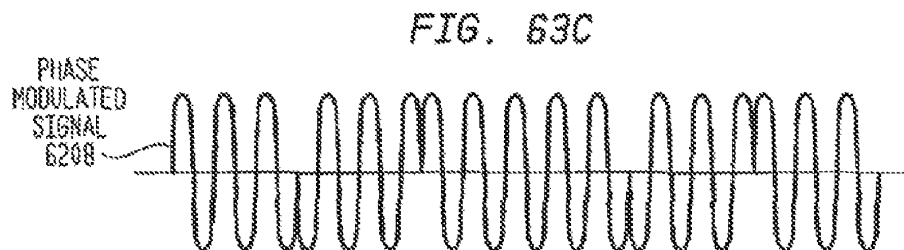
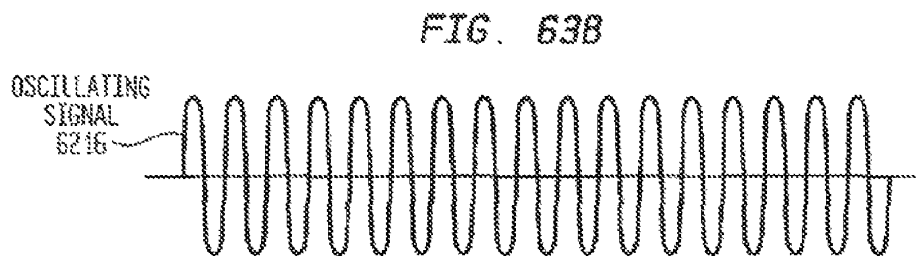
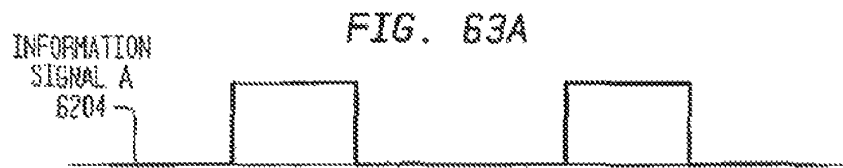


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FIG. 63E

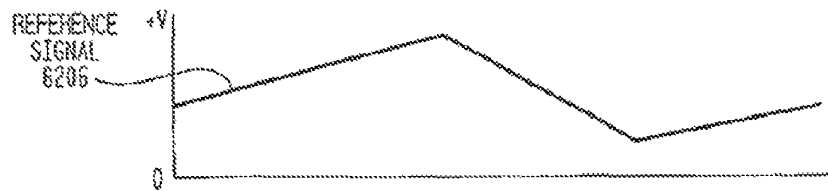


FIG. 63F

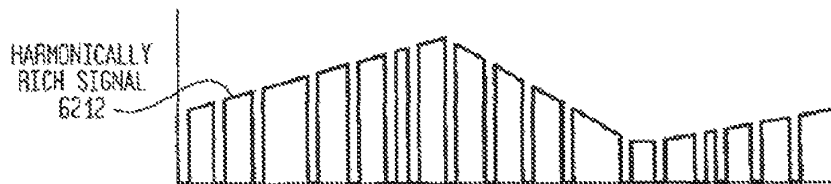


FIG. 63G

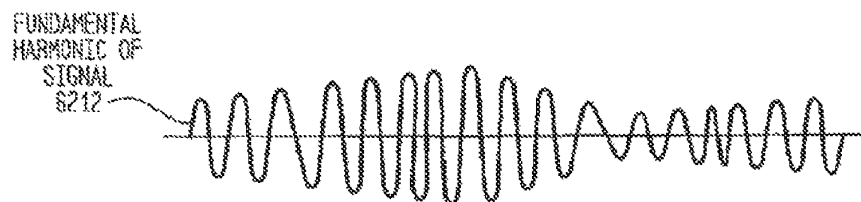
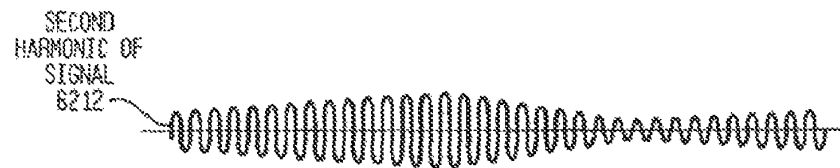


FIG. 63H



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FIG. 64A

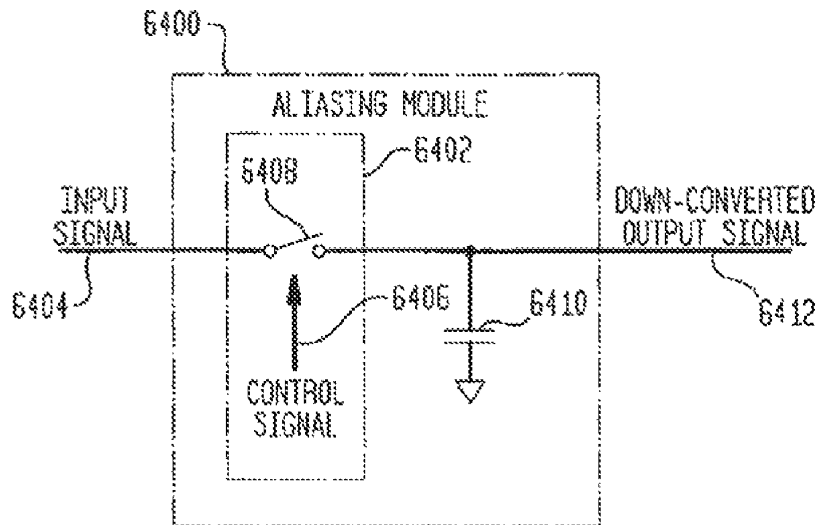
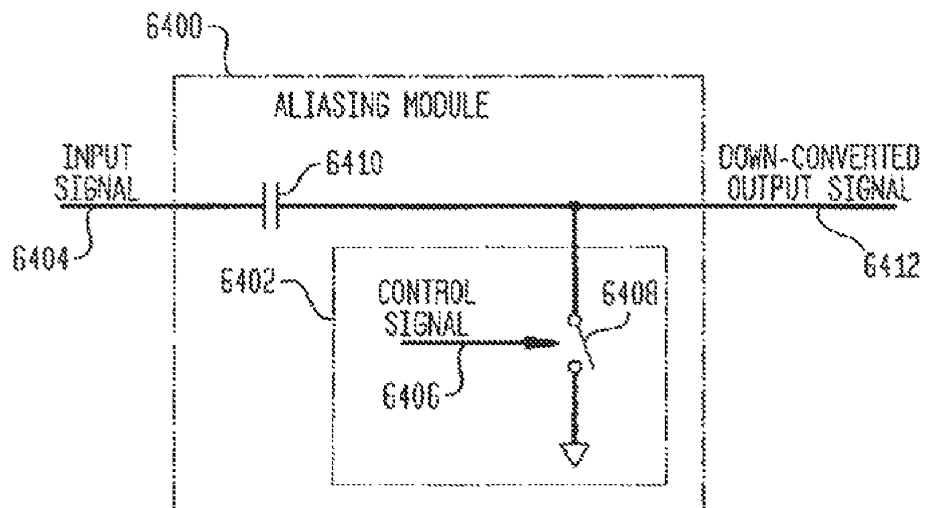


FIG. 64A-1



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FIG. 64B

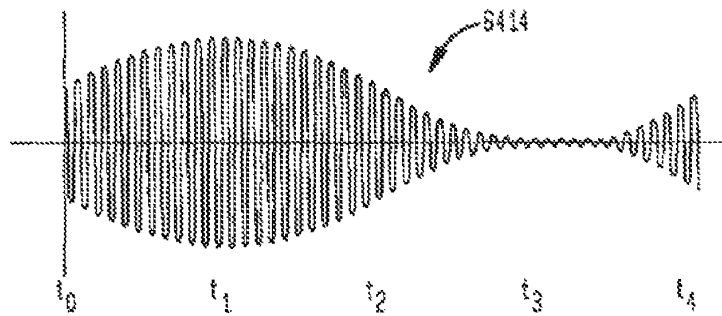


FIG. 64C

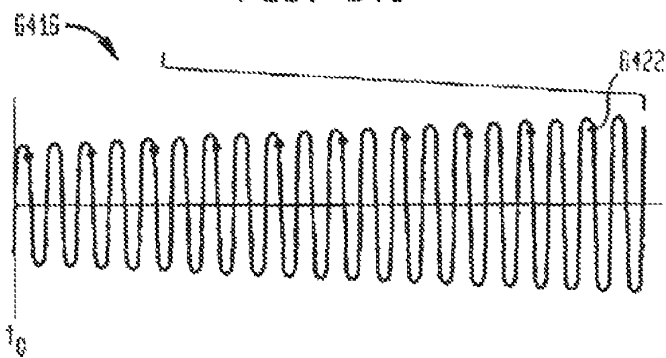


FIG. 64D

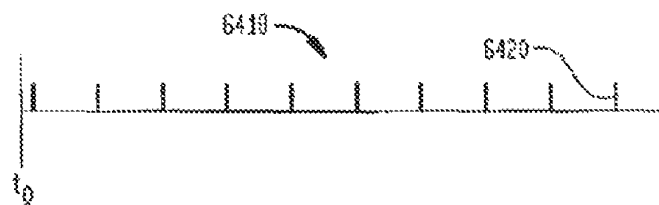


FIG. 64E

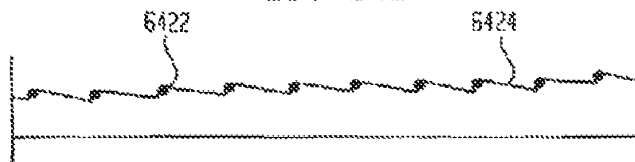
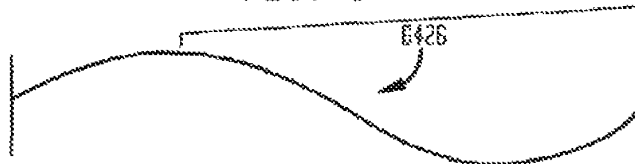


FIG. 64F



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**METHOD AND SYSTEM FOR FREQUENCY  
UP-CONVERSION****CROSS REFERENCE TO RELATED  
APPLICATIONS**

The present application is a continuation of U.S. patent application Ser. No. 12/435,595, "Method and System for Frequency Down-Conversion and Frequency Up-Conversion," filed May 5, 2009, now U.S. Pat. No. 8,019,291, which is a continuation of U.S. patent application Ser. No. 11/802,389, "Frequency Up-Conversion Using a Harmonic Generation and Extraction Module," filed May 22, 2007, U.S. Pat. No. 7,546,096, which is a divisional of U.S. patent application Ser. No. 10/086,367, "Method and System for Frequency Up-Conversion," filed Mar. 4, 2002, U.S. Pat. No. 7,236,754, which is a continuation of U.S. patent application Ser. No. 09/379,497, "Method for Output Signal Generation," filed Aug. 23, 1999, U.S. Pat. No. 6,353,735, which is a continuation of U.S. patent application Ser. No. 09/176,154, "Method and System for Frequency Up-Conversion," filed Oct. 21, 1998, U.S. Pat. No. 6,091,940, all of which are herein incorporated by reference in their entireties.

The following applications of common assignee are related to the present application and are herein incorporated by reference in their entireties:

U.S. patent application Ser. No. 09/176,022, "Method and System for Down-Converting Electromagnetic Signals," filed Oct. 21, 1998, U.S. Pat. No. 6,061,551.

U.S. patent application Ser. No. 09/176,415, "Method and System for Ensuring Reception of a Communications Signal," filed Oct. 21, 1998, U.S. Pat. No. 6,061,555.

U.S. patent application Ser. No. 09/175,966, "Integrated Frequency Translation And Selectivity," filed Oct. 21, 1998, U.S. Pat. No. 6,049,706.

U.S. patent application Ser. No. 09/176,027, "Universal Frequency Translation, and Applications of Same," filed Oct. 21, 1998 (abandoned).

**BACKGROUND OF THE INVENTION****1. Field of the Invention**

The present invention is generally directed to frequency up-conversion of electromagnetic (EM) signals.

**2. Related Art**

Modern day communication systems employ components such as transmitters and receivers to transmit information from a source to a destination. To accomplish this transmission, information is imparted on a carrier signal and the carrier signal is then transmitted. Typically, the carrier signal is at a frequency higher than the baseband frequency of the information signal. Typical ways that the information is imparted on the carrier signal are called modulation.

Three widely used modulation schemes include: frequency modulation (FM), where the frequency of the carrier wave changes to reflect the information that has been modulated on the signal; phase modulation (PM), where the phase of the carrier signal changes to reflect the information imparted on it; and amplitude modulation (AM), where the amplitude of the carrier signal changes to reflect the information. Also, these modulation schemes are used in combination with each other (e.g., AM combined with FM and AM combined with PM).

**SUMMARY OF THE INVENTION**

The present invention is directed to methods and systems to up-convert a signal from a lower frequency to a higher frequency, and applications thereof.

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In one embodiment, the invention uses a stable, low frequency signal to generate a higher frequency signal with a frequency and phase that can be used as stable references.

In another embodiment, the present invention is used as a transmitter. In this embodiment, the invention accepts an information signal at a baseband frequency and transmits a modulated signal at a frequency higher than the baseband frequency.

The methods and systems of transmitting vary slightly depending on the modulation scheme being used. For some embodiments using frequency modulation (FM) or phase modulation (PM), the information signal is used to modulate an oscillating signal to create a modulated intermediate signal. If needed, this modulated intermediate signal is "shaped" to provide a substantially optimum pulse-width-to-period ratio. This shaped signal is then used to control a switch which opens and closes as a function of the frequency and pulse width of the shaped signal. As a result of this opening and closing, a signal that is harmonically rich is produced with each harmonic of the harmonically rich signal being modulated substantially the same as the modulated intermediate signal. Through proper filtering, the desired harmonic (or harmonics) is selected and transmitted.

For some embodiments using amplitude modulation (AM), the switch is controlled by an unmodulated oscillating signal (which may, if needed, be shaped). As the switch opens and closes, it gates a reference signal which is the information signal. In an alternate implementation, the information signal is combined with a bias signal to create the reference signal, which is then gated. The result of the gating is a harmonically rich signal having a fundamental frequency substantially proportional to the oscillating signal and an amplitude substantially proportional to the amplitude of the reference signal. Each of the harmonics of the harmonically rich signal also have amplitudes proportional to the reference signal, and are thus considered to be amplitude modulated. Just as with the FM/PM embodiments described above, through proper filtering, the desired harmonic (or harmonics) is selected and transmitted.

Further features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying figures. The left-most digit(s) of a reference number typically identifies the figure in which the reference number first appears.

**BRIEF DESCRIPTION OF THE FIGURES**

FIG. 1 illustrates a circuit for a frequency modulation (FM) transmitter;

FIGS. 2A, 2B, and 2C illustrate typical waveforms associated with the FIG. 1 FM circuit for a digital information signal;

FIG. 3 illustrates a circuit for a phase modulation (PM) transmitter;

FIGS. 4A, 4B, and 4C illustrate typical waveforms associated with the FIG. 3 PM circuit for a digital information signal;

FIG. 5 illustrates a circuit for an amplitude modulation (AM) transmitter;

FIGS. 6A, 6B, and 6C illustrate typical waveforms associated with the FIG. 5 AM circuit for a digital information signal;

FIG. 7 illustrates a circuit for an in-phase/quadrature-phase modulation ("I/Q") transmitter;

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FIGS. 8A, 8B, 8C, 8D, and 8E illustrate typical waveforms associated with the FIG. 7 “I/Q” circuit for digital information signal;

FIG. 9 illustrates the high level operational flowchart of a transmitter according to an embodiment of the present invention;

FIG. 10 illustrates the high level structural block diagram of the transmitter of an embodiment of the present invention;

FIG. 11 illustrates the operational flowchart of a first embodiment (i.e., FM mode) of the present invention;

FIG. 12 illustrates an exemplary structural block diagram of the first embodiment (i.e., FM mode) of the present invention;

FIG. 13 illustrates the operational flowchart of a second embodiment (i.e., PM mode) of the present invention;

FIG. 14 illustrates an exemplary structural block diagram of the second embodiment (i.e., PM mode) of the present invention;

FIG. 15 illustrates the operational flowchart of a third embodiment (i.e., AM mode) of the present invention;

FIG. 16 illustrates an exemplary structural block diagram of the third embodiment (i.e., AM mode) of the present invention;

FIG. 17 illustrates the operational flowchart of a fourth embodiment (i.e., “I/Q” mode) of the present invention;

FIG. 18 illustrates an exemplary structural block diagram of the fourth embodiment (i.e., “I/Q” mode) of the present invention;

FIGS. 19A-19I illustrate exemplary waveforms (for a frequency modulation mode operating in a frequency shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram;

FIGS. 20A, 20B, 20C illustrate typical waveforms associated with the FIG. 1 FM circuit for an analog information signal;

FIGS. 21A, 21B, 21C illustrate typical waveforms associated with the FIG. 3 PM circuit for an analog information signal;

FIGS. 22A, 22B, 22C illustrate typical waveforms associated with the FIG. 5 AM circuit for an analog information signal;

FIG. 23 illustrates an implementation example of a voltage controlled oscillator (VCO);

FIG. 24 illustrates an implementation example of a local oscillator (LO);

FIG. 25 illustrates an implementation example of a phase shifter;

FIG. 26 illustrates an implementation example of a phase modulator;

FIG. 27 illustrates an implementation example of a summing amplifier;

FIGS. 28A-28C illustrate an implementation example of a switch module for the FM and PM modes;

FIG. 29A-29C illustrate an example of the switch module of FIGS. 28A-28C wherein the switch is a GaAsFET;

FIGS. 30A-30C illustrate an example of a design to ensure symmetry for a GaAsFET implementation in the FM and PM modes;

FIGS. 31A-31C illustrate an implementation example of a switch module for the AM mode;

FIGS. 32A-32C illustrate the switch module of FIGS. 31A-31C wherein the switch is a GaAsFET;

FIGS. 33A-33C illustrate an example of a design to ensure symmetry for a GaAsFET implementation in the AM mode;

FIG. 34 illustrates an implementation example of a summer;

FIG. 35 illustrates an implementation example of a filter;

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FIG. 36 is a representative spectrum demonstrating the calculation of “Q”;

FIGS. 37A and 37B are representative examples of filter circuits;

FIG. 38 illustrates an implementation example of a transmission module;

FIG. 39A shows a first exemplary pulse shaping circuit using digital logic devices for a squarewave input from an oscillator;

FIGS. 39B, 39C, and 39D illustrate waveforms associated with the FIG. 39A circuit;

FIG. 40A shows a second exemplary pulse shaping circuit using digital logic devices for a squarewave input from an oscillator;

FIGS. 40B, 40C, and 40D illustrate waveforms associated with the FIG. 40A circuit;

FIG. 41 shows a third exemplary pulse shaping circuit for any input from an oscillator;

FIGS. 42A, 42B, 42C, 42D, and 42E illustrate representative waveforms associated with the FIG. 41 circuit;

FIG. 43 shows the internal circuitry for elements of FIG. 41 according to an embodiment of the invention;

FIGS. 44A-44G illustrate exemplary waveforms (for a pulse modulation mode operating in a pulse shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram, highlighting the characteristics of the first three harmonics;

FIGS. 45A-45F illustrate exemplary waveforms (for an amplitude modulation mode operating in an amplitude shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram, highlighting the characteristics of the first three harmonics;

FIG. 46 illustrates an implementation example of a harmonic enhancement module;

FIG. 47 illustrates an implementation example of an amplifier module;

FIGS. 48A and 48B illustrate exemplary circuits for a linear amplifier;

FIG. 49 illustrates a typical superheterodyne receiver;

FIG. 50 illustrates a transmitter according to an embodiment of the present invention in a transceiver circuit with a typical superheterodyne receiver in a full-duplex mode;

FIGS. 51A, 51B, 51C, and 51D illustrate a transmitter according to an embodiment of the present invention in a transceiver circuit using a common oscillator with a typical superheterodyne receiver in a half-duplex mode;

FIG. 52 illustrates an exemplary receiver using universal frequency down conversion techniques according to an embodiment;

FIG. 53 illustrates an exemplary transmitter of the present invention;

FIGS. 54A, 54B, and 54C illustrate an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a half-duplex mode for the FM and PM modulation embodiment;

FIG. 55 illustrates an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a half-duplex mode for the AM modulation embodiment;

FIG. 56 illustrates an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a full-duplex mode;

FIGS. 57A-57C illustrate an exemplary transmitter of the present invention being used in frequency modulation, phase modulation, and amplitude modulation embodiments, including a pulse shaping circuit and an amplifier module;

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FIG. 58 illustrates harmonic amplitudes for a pulse-width-to-period ratio of 0.01;

FIG. 59 illustrates harmonic amplitudes for a pulse-width-to-period ratio of 0.0556;

FIG. 60 is a table that illustrates the relative amplitudes of the first 50 harmonics for six exemplary pulse-width-to-period ratios;

FIG. 61 is a table that illustrates the relative amplitudes of the first 25 harmonics for six pulse-width-to-period ratios optimized for the 1<sup>st</sup> through 10<sup>th</sup> subharmonics;

FIG. 62 illustrates an exemplary structural block diagram for an alternative embodiment of the present invention (i.e., a mode wherein AM is combined with PM);

FIGS. 63A-63H illustrate exemplary waveforms (for the embodiment of FIG. 62) at a plurality of points in an exemplary high level circuit diagram, highlighting the characteristics of the first two harmonics;

FIGS. 64A and 64A1 illustrate exemplary implementations of aliasing modules; and

FIGS. 64B-64F illustrate exemplary waveforms at a plurality of points in the FIGS. 64A and 64A1 circuits.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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Third Embodiment: The Transmitter of the Present Invention Being Used with a Universal Frequency Down Converter in a Full-Duplex Mode.

Other Embodiments and Implementations.

Summary Description of Down-conversion Using a Universal Frequency Translation Module.

Designing a Transmitter According to an Embodiment of the Present Invention.

Frequency of the Transmission Signal.

Characteristics of the Transmission Signal.

Modulation Scheme.

Characteristics of the Information Signal.

Characteristic of the Oscillating Signal.

Frequency of the Oscillating Signal.

Pulse Width of the String of Pulses.

Design of the Pulse Shaping Circuit.

Selection of the Switch.

Design of the Filter.

Selection of an Amplifier.

Design of the Transmission Module.

Terminology

Various terms used in this application are generally described in this section. Each description in this section is provided for illustrative and convenience purposes only, and is not limiting. The meaning of these terms will be apparent to persons skilled in the relevant art(s) based on the entirety of the teachings provided herein.

Amplitude Modulation (AM): A modulation technique wherein the amplitude of the carrier signal is shifted (i.e., varied) as a function of the information signal. The frequency of the carrier signal typically remains constant. A subset of AM is referred to as "amplitude shift keying" which is used primarily for digital communications where the amplitude of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

Analog signal: A signal in which the information contained therein is continuous as contrasted to discrete, and represents a time varying physical event or quantity. The information content is conveyed by varying at least one characteristic of the signal, such as but not limited to amplitude, frequency, or phase, or any combinations thereof.

Baseband signal: Any generic information signal desired for transmission and/or reception. As used herein, it refers to both the information signal that is generated at a source prior to any transmission (also referred to as the modulating baseband signal), and to the signal that is to be used by the recipient after transmission (also referred to as the demodulated baseband signal).

Carrier signal: A signal capable of carrying information. Typically, it is an electromagnetic signal that can be varied through a process called modulation. The frequency of the carrier signal is referred to as the carrier frequency. A communications system may have multiple carrier signals at different carrier frequencies.

Control a switch: Causing a switch to open and close. The switch may be, without limitation, mechanical, electrical, electronic, optical, etc., or any combination thereof. Typically, it is controlled by an electrical or electronic input. If the switch is controlled by an electronic signal, it is typically a different signal than the signals connected to either terminal of the switch.

Demodulated baseband signal: The baseband signal that is to be used by the recipient after transmission. Typically it has been down converted from a carrier signal and has been demodulated. The demodulated baseband signal should

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closely approximate the information signal (i.e., the modulating baseband signal) in frequency, amplitude, and information.

Demodulation: The process of removing information from a carrier or intermediate frequency signal.

Digital signal: A signal in which the information contained therein has discrete states as contrasted to a signal that has a property that may be continuously variable.

Direct down conversion: A down conversion technique wherein a received signal is directly down converted and demodulated, if applicable, from the original transmitted frequency (i.e., a carrier frequency) to baseband without having an intermediate frequency.

Down conversion: A process for performing frequency translation in which the final frequency is lower than the initial frequency.

Drive a switch: Same as control a switch.

Frequency Modulation (FM): A modulation technique wherein the frequency of the carrier signal is shifted (i.e., varied) as a function of the information signal. A subset of FM is referred to as "frequency shift keying" which is used primarily for digital communications where the frequency of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

Harmonic: A harmonic is a frequency or tone that, when compared to its fundamental or reference frequency or tone, is an integer multiple of it. In other words, if a periodic waveform has a fundamental frequency of "f" (also called the first harmonic), then its harmonics may be located at frequencies of "n-f," where "n" is 2, 3, 4, etc. The harmonic corresponding to n=2 is referred to as the second harmonic, the harmonic corresponding to n=3 is referred to as the third harmonic, and so on.

In-phase ("I") signal: The signal typically generated by an oscillator. It has not had its phase shifted and is often represented as a sine wave to distinguish it from a "Q" signal. The "I" signal can, itself, be modulated by any means. When the "I" signal is combined with a "Q" signal, the resultant signal is referred to as an "I/Q" signal.

In-phase/Quadrature-phase ("I/Q") signal: The signal that results when an "I" signal is summed with a "Q" signal. Typically, both the "I" and "Q" signals have been phase modulated, although other modulation techniques may also be used, such as amplitude modulation. An "I/Q" signal is used to transmit separate streams of information simultaneously on a single transmitted carrier. Note that the modulated "I" signal and the modulated "Q" signal are both carrier signals having the same frequency. When combined, the resultant "I/Q" signal is also a carrier signal at the same frequency.

Information signal: The signal that contains the information that is to be transmitted. As used herein, it refers to the original baseband signal at the source. When it is intended that the information signal modulate a carrier signal, it is also referred to as the "modulating baseband signal." It may be voice or data, analog or digital, or any other signal or combination thereof.

Intermediate frequency (IF) signal: A signal that is at a frequency between the frequency of the baseband signal and the frequency of the transmitted signal.

Modulation: The process of varying one or more physical characteristics of a signal to represent the information to be transmitted. Three commonly used modulation techniques are frequency modulation, phase modulation, and amplitude modulation. There are also variations, subsets, and combinations of these three techniques.

Operate a switch: Same as control a switch.

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Phase Modulation (PM): A modulation technique wherein the phase of the carrier signal is shifted (i.e., varied) as a function of the information signal. A subset of pm is referred to as "phase shift keying" which is used primarily for digital communications where the phase of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

Quadrature-phase ("Q") signal: A signal that is out of phase with an in-phase ("I") signal. The amount of phase shift is predetermined for a particular application, but in a typical implementation, the "Q" signal is 90° out of phase with the "I" signal. Thus, if the "I" signal were a sine wave, the "Q" signal would be a cosine wave. When discussed together, the "I" signal and the "Q" signal have the same frequencies.

Spectrum: Spectrum is used to signify a continuous range of frequencies, usually wide, within which electromagnetic (EM) waves have some specific common characteristic. Such waves may be propagated in any communication medium, both natural and manmade, including but not limited to air, space, wire, cable, liquid, waveguide, microstrip, stripline, optical fiber, etc. The EM spectrum includes all frequencies greater than zero hertz.

Subharmonic: A subharmonic is a frequency or tone that is an integer submultiple of a referenced fundamental frequency or tone. That is, a subharmonic frequency is the quotient obtained by dividing the fundamental frequency by an integer. For example, if a periodic waveform has a frequency of "f" (also called the "fundamental frequency" or first subharmonic), then its subharmonics have frequencies of " $f/n$ ," where n is 2, 3, 4, etc. The subharmonic corresponding to n=2 is referred to as the second subharmonic, the subharmonic corresponding to n=3 is referred to as the third subharmonic, and so on. A subharmonic itself has possible harmonics, and the  $i^{th}$  harmonic of the  $j^{th}$  subharmonic will be at the fundamental frequency of the original periodic waveform. For example, the third subharmonic (which has a frequency of " $f/3$ ") may have harmonics at integer multiples of itself (i.e., a second harmonic at " $2 \cdot f/3$ ," a third harmonic at " $3 \cdot f/3$ ," and so on). The third harmonic of the third subharmonic of the original signal (i.e., " $3 \cdot f/3$ ") is at the frequency of the original signal.

Trigger a switch: Same as control a switch.

Up conversion: A process for performing frequency translation in which the final frequency is higher than the initial frequency.

## 2. Overview of the Invention

The present invention is directed to systems and methods for frequency up-conversion, and applications thereof.

In one embodiment, the frequency up-converter of the present invention is used as a stable reference frequency source in a phase comparator or in a frequency comparator. This embodiment of the present invention achieves this through the use of a stable, low frequency local oscillator, a switch, and a filter. Because it up-converts frequency, the present invention can take advantage of the relatively low cost of low frequency oscillators to generate stable, high frequency signals.

In a second embodiment, the frequency up-converter is used as a system and method for transmitting an electromagnetic (EM) signal.

Based on the discussion contained herein, one skilled in the relevant art(s) will recognize that there are other, alternative embodiments in which the frequency up-converter of the present invention could be used in other applications, and that these alternative embodiments fall within the scope of the present invention.

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For illustrative purposes, various modulation examples are discussed below. However, it should be understood that the invention is not limited by these examples. Other modulation techniques that might be used with the present invention will be apparent to persons skilled in the relevant art(s) based on the teaching contained herein.

Also for illustrative purposes, frequency up-conversion according to the present invention is described below in the context of a transmitter. However, the invention is not limited to this embodiment. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

### 2.1 Discussion of Modulation Techniques.

Techniques by which information can be imparted onto EM signals to be transmitted are called modulation. These techniques are generally well known to one skilled in the relevant art(s), and include, but are not limited to, frequency modulation (FM), phase modulation (PM), amplitude modulation (AM), quadrature-phase shift keying (QPSK), frequency shift keying (FSK), phase shift keying (PSK), amplitude shift keying (ASK), etc., and combinations thereof. These last three modulation techniques, FSK, PSK, and ASK, are subsets of FM, PM, and AM, respectively, and refer to circuits having discrete input signals (e.g., digital input signals).

For illustrative purposes only, the circuits and techniques described below all refer to the EM broadcast medium. However, the invention is not limited by this embodiment. Persons skilled in the relevant art(s) will recognize that these same circuits and techniques can be used in all transmission media (e.g., over-the-air broadcast, point-to-point cable, etc.).

### 2.2 Explanation of Exemplary Circuits and Waveforms.

#### 2.2.1 Frequency Modulation.

FIG. 1 illustrates an example of a frequency modulation (FM) circuit 100 and FIGS. 2A, 2B, and 2C, and FIGS. 20A, 20B, and 20C illustrate examples of waveforms at several points in FM circuit 100. In an FM system, the frequency of a carrier signal, such as an oscillating signal 202 (FIG. 2B and FIG. 20B), is varied to represent the data to be communicated, such as information signals 102 of FIGS. 2A and 2002 of FIG. 20A. In FIG. 20A, information signal 2002 is a continuous signal (i.e., an analog signal), and in FIG. 2A, information signal 102 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 102, the FM circuit 100 is referred to as a frequency shift keying (FSK) system, which is a subset of an FM system.

Frequency modulation circuit 100 receives an information signal 102, 2002 from a source (not shown). Information signal 102, 2002 can be amplified by an optional amplifier 104 and filtered by an optional filter 114 and is the voltage input that drives a voltage controlled oscillator (VCO) 106. Within VCO 106, an oscillating signal 202 (seen on FIG. 2B and FIG. 20B) is generated. The purpose of VCO 106 is to vary the frequency of oscillating signal 202 as a function of the input voltage, i.e., information signal 102, 2002. The output of VCO 106 is a modulated signal shown as modulated signal 108 (FIG. 2C) when the information signal is the digital information signal 102 and shown as modulated signal 2004 (FIG. 20C) when the information signal is the analog signal 2002. Modulated signal 108, 2004 is at a relatively low frequency (e.g., generally between 50 MHz and 100 MHz) and can have its frequency increased by an optional frequency multiplier 110 (e.g., to 900 MHz, 1.8 GHz) and have its amplitude increased by an optional amplifier 116. The output

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of optional frequency multiplier 110 and/or optional amplifier 116 is then transmitted by an exemplary antenna 112.

#### 2.2.2 Phase Modulation.

FIG. 3 illustrates an example of a phase modulation (PM) circuit 300 and FIGS. 4A, 4B, and 4C, and FIGS. 21A, 21B, and 21C illustrate examples of waveforms at several points in PM circuit 300. In a PM system, the phase of a carrier signal, such as a local oscillator (LO) output 308 (FIG. 4B and FIG. 21B), is varied to represent the data to be communicated, such as an information signals 302 of FIGS. 4A and 2102 of FIG. 21A. In FIG. 21A, information signal 2102 is a continuous signal (i.e., an analog signal), and in FIG. 4A, information signal 302 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 302, the PM circuit is referred to as a phase shift keying (PSK) system. This is the typical implementation, and is a subset of a PM system.

Phase modulation circuit 300 receives information signal 302, 2102 from a source (not shown). Information signal 302, 2102 can be amplified by an optional amplifier 304 and filtered by an optional filter 318 and is routed to a phase modulator 306. Also feeding phase modulator 306 is LO output 308 of a local oscillator 310. LO output 308 is shown on FIG. 4B and FIG. 21B. Local oscillators, such as local oscillator 310, output an electromagnetic wave at a predetermined frequency and amplitude.

The output of phase modulator 306 is a modulated signal shown as a phase modulated signal 312 (FIG. 4C) when the information signal is the discrete information signal 302 and shown as a phase modulated signal 2104 (FIG. 21C) when the information signal is the analog information signal 2102. The purpose of phase modulator 306 is to change the phase of LO output 308 as a function of the value of information signal 302, 2102. That is, for example in a PSK mode, if LO output 308 were a sine wave, and the value of information signal 302 changed from a binary high to a binary low, the phase of LO output 308 would change from a sine wave with a zero phase to a sine wave with, for example, a phase of 180°. The result of this phase change would be phase modulated signal 312 of FIG. 4C which would have the same frequency as LO output 308, but would be out of phase by 180° in this example. For a PSK system, the phase changes in phase modulated signal 312 that are representative of the information in information signal 302 can be seen by comparing waveforms 302, 308, and 312 on FIGS. 4A, 4B, and 4C. For the case of an analog information signal 2102 of FIG. 21A, the phase of LO output 308 of FIG. 21B changes continuously as a function of the amplitude of the information signal 2102. That is, for example, as information signal 2102 increases from a value of “X” to “X+δx”, the PM signal 2104 of FIG. 21C changes from a signal which may be represented by the equation  $\sin(\omega t)$  to a signal which can be represented by the equation  $\sin(\omega t + \phi)$ , where  $\phi$  is the phase change associated with a change of  $\delta x$  in information signal 2102. For an analog PM system, the phase changes in phase modulated signal 2104 that are representative of the information in information signal 2102 can be seen by comparing waveforms 2102, 308, and 2104 on FIGS. 21A, 21B, and 21C.

After information signal 302, 2102 and LO output 308 have been modulated by phase modulator 306, phase modulated signal 312, 2104 can be routed to an optional frequency multiplier 314 and optional amplifier 320. The purpose of optional frequency multiplier 314 is to increase the frequency of phase modulated signal 312 from a relatively low frequency (e.g., 50 MHz to 100 MHz) to a desired broadcast frequency (e.g., 900 MHz, 1.8 GHz). Optional amplifier 320

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raises the signal strength of phase modulated signal 312, 2104 to a desired level to be transmitted by an exemplary antenna 316.

#### 2.2.3 Amplitude Modulation.

FIG. 5 illustrates an example of an amplitude modulation (AM) circuit 500 and FIGS. 6A, 6B, and 6C, and FIGS. 22A, 22B, and 22C illustrate examples of waveforms at several points in AM circuit 500. In an AM system, the amplitude of a carrier signal, such as a local oscillator (LO) signal 508 (FIG. 6B and FIG. 22B), is varied to represent the data to be communicated, such as information signals 502 of FIGS. 6A and 2202 of FIG. 22A. In FIG. 22A, information signal 2202 is a continuous signal (i.e., an analog signal), and in FIG. 6A, information signal 502 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 502, the AM circuit is referred to as an amplitude shift keying (ASK) system, which is a subset of an AM system.

Amplitude modulation circuit 500 receives information signal 502 from a source (not shown). Information signal 502, 2202 can be amplified by an optional amplifier 504 and filtered by an optional filter 518. Amplitude modulation circuit 500 also includes a local oscillator (LO) 506 which has an LO output 508. Information signal 502, 2202 and LO output 508 are then multiplied by a multiplier 510. The purpose of multiplier 510 is to cause the amplitude of LO output 508 to vary as a function of the amplitude of information signal 502, 2202. The output of multiplier 510 is a modulated signal shown as amplitude modulated signal 512 (FIG. 6C) when the information signal is the digital information signal 502 and shown as modulated signal 2204 (FIG. 22C) when the information signal is the analog information signal 2202. AM signal 512, 2204 can then be routed to an optional frequency multiplier 514 where the frequency of AM signal 512, 2204 is increased from a relatively low level (e.g., 50 MHz to 100 MHz) to a higher level desired for broadcast (e.g., 900 MHz, 1.8 GHz) and an optional amplifier 520, which increases the signal strength of AM signal 512, 2204 to a desired level for broadcast by an exemplary antenna 516.

#### 2.2.4 In-Phase/Quadrature-Phase Modulation.

FIG. 7 illustrates an example of an in-phase/quadrature-phase (“I/Q”) modulation circuit 700 and FIGS. 8A, 8B, 8C, 8D, and 8E illustrate examples of waveforms at several points in “I/Q” modulation circuit 700. In this technique, which increases bandwidth efficiency, separate information signals can be simultaneously transmitted on carrier signals that are out of phase with each other. That is, a first information signal 702 of FIG. 8A can be modulated onto the in-phase (“I”) oscillator signal 710 of FIG. 8B and a second information signal 704 of FIG. 8C can be modulated onto the quadrature-phase (“Q”) oscillator signal 712 of FIG. 8D. The “I” modulated signal is combined with the “Q” modulated signal and the resulting “I/Q” modulated signal is then transmitted. In a typical usage, both information signals are digital, and both are phase modulated onto the “I” and “Q” oscillating signals. One skilled in the relevant art(s) will recognize that the “I/Q” mode can also work with analog information signals, with combinations of analog and digital signals, with other modulation techniques, or any combinations thereof.

This “I/Q” modulation system uses two PM circuits together in order to increase the bandwidth efficiency. As stated above, in a PM circuit, the phase of an oscillating signal, such as 710 (or 712) (FIG. 8B or 8D), is varied to represent the data to be communicated, such as an information signal such as 702 (or 704). For ease of understanding and display, the discussion herein will describe the more typical use of the “I/Q” mode, that is, with digital information

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signals and phase modulation on both oscillating signals. Thus, both signal streams are phase shift keying (PSK), which is a subset of PM.

"I/Q" modulation circuit 700 receives an information signal 702 from a first source (not shown) and an information signal 704 from a second source (not shown). Examples of information signals 702 and 704 are shown in FIGS. 8A and 8C. Information signals 702 and 704 can be amplified by optional amplifiers 714 and 716 and filtered by optional filters 734 and 736. It is then routed to phase modulators 718 and 720. Also feeding phase modulators 718 and 720 are oscillating signals 710 and 712. Oscillating signal 710 was generated by a local oscillator 706, and is shown in FIG. 8B, and oscillating signal 712 is the phase shifted output of local oscillator 706. Local oscillators, such as local oscillator 706, output an electromagnetic wave at a predetermined frequency and amplitude.

The output of phase modulator 718 is a phase modulated signal 722 which is shown using a dotted line as one of the waveforms in FIG. 8E. Similarly, the output of phase modulator 720, which operates in a manner similar to phase modulator 718, is a phase modulated signal 724 which is shown using a solid line as the other waveform in FIG. 8E. The effect of phase modulators 718 and 720 on oscillating signals 710 and 712 is to cause them to change phase. As stated above, the system shown here is a PSK system, and as such, the phase of oscillating signals 710 and 712 is shifted by phase modulators 718 and 720 by a discrete amount as a function of information signals 702 and 704.

For simplicity of discussion and ease of display, oscillating signal 710 is shown on FIG. 8B as a sine wave and is referred to as the "I" signal in the "I/Q" circuit 700. After the output of oscillator 706 has gone through a phase shifter 708, shown here as shifting the phase by  $-\pi/2$ , oscillating signal 712 is a cosine wave, shown on FIG. 8D, and is referred to as the "Q" signal in the "I/Q" circuit. Again, for ease of display, phase modulators 718 and 720 are shown as shifting the phase of the respective oscillating signals 710 and 712 by  $180^\circ$ . This is seen on FIG. 8E. Modulated signal 722 is summed with modulated signal 724 by a summer 726. The output of summer 726 is the arithmetic sum of modulated signal 722 and 724 and is an "I/Q" signal 728. (For clarity of the display on FIG. 8E, the combined signal 728 is not shown. However, one skilled in the relevant art(s) will recognize that the arithmetic sum of 2 sinusoidal waves having the same frequency is also a sinusoidal wave at that frequency.)

"I/Q" signal 728 can then be routed to an optional frequency multiplier 730, where the frequency of "I/Q" signal 718 is increased from a relatively low level (e.g., 50 MHz to 100 MHz) to a higher level desired for broadcast (e.g., 900 MHz, 1.8 GHz), and to an optional amplifier 738 which increases the signal strength of "I/Q" signal 728 to a desired level for broadcast by an exemplary antenna 732.

### 2.3 Features of the Invention.

As apparent from the above, several frequencies are involved in a communications system. The frequency of the information signal is relatively low. The frequency of the local oscillator (both the voltage controlled oscillator as well as the other oscillators) is higher than that of the information signal, but typically not high enough for efficient transmission. A third frequency, not specifically mentioned above, is the frequency of the transmitted signal which is greater than or equal to the frequency of the oscillating signal. This is the frequency that is routed from the optional frequency multipliers and optional amplifiers to the antennas in the previously described circuits.

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Typically, in the transmitter subsystem of a communications system, upconverting the information signal to broadcast frequency requires, at least, filters, amplifiers, and frequency multipliers. Each of these components is costly, not only in terms of the purchase price of the component, but also because of the power required to operate them.

The present invention provides a more efficient means for producing a modulated carrier for transmission, uses less power, and requires fewer components. These and additional advantages of the present invention will be apparent from the following description.

### 3. Frequency Up-Conversion.

The present invention is directed to systems and methods for frequency up-conversion and applications of the same. In one embodiment, the frequency up-converter of the present invention allows the use of a stable, low frequency oscillator to generate a stable high frequency signal that, for example and without limitation, can be used as a reference signal in a phase comparator or a frequency comparator. In another embodiment, the up-converter of the present invention is used in a transmitter. The invention is also directed to a transmitter. Based on the discussion contained herein, one skilled in the relevant art(s) will recognize that there are other, alternative embodiments and applications in which the frequency up-converter of the present invention could be used, and that these alternative embodiments and applications fall within the scope of the present invention.

For illustrative purposes, frequency up-conversion according to the present invention is described below in the context of a transmitter. However, as apparent from the preceding paragraph, the invention is not limited to this embodiment.

The following sections describe methods related to a transmitter and frequency up-converter. Structural exemplary embodiments for achieving these methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

#### 3.1. High Level Description.

This section (including its subsections) provides a high-level description of up-converting and transmitting signals according to the present invention. In particular, an operational process of frequency up-conversion in the context of transmitting signals is described at a high-level. The operational process is often represented by flowcharts. The flowcharts are presented herein for illustrative purposes only, and are not limiting. In particular, the use of flowcharts should not be interpreted as limiting the invention to discrete or digital operation. In practice, those skilled in the relevant art(s) will appreciate, based on the teachings contained herein, that the invention can be achieved via discrete operation, continuous operation, or any combination thereof. Furthermore, the flow of control represented by the flowcharts is also provided for illustrative purposes only, and it will be appreciated by persons skilled in the relevant art(s) that other operational control flows are within the scope and spirit of the invention.

Also, a structural implementation for achieving this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of

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such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

### 3.1.1 Operational Description.

The flow chart **900** of FIG. **9** demonstrates the operational method of frequency up-conversion in the context of transmitting a signal according to an embodiment of the present invention. The invention is directed to both frequency up-conversion and transmitting signals as represented in FIG. **9**. Representative waveforms for signals generated in flow chart **900** are depicted in FIG. **19**. For purposes of illustrating the high level operation of the invention, frequency modulation of a digital information signal is depicted. The invention is not limited to this exemplary embodiment. One skilled in the relevant art(s) will appreciate that other modulation modes could alternatively be used (as described in later sections).

In step **902**, an information signal **1902** (FIG. **19A**) is generated by a source. This information signal may be analog, digital, and any combination thereof, or anything else that is desired to be transmitted, and is at the baseband frequency. As described below, the information signal **1902** is used to modulate an intermediate signal **1904**. Accordingly, the information signal **1902** is also herein called a modulating baseband information signal. In the example of FIG. **19A**, the information signal **1902** is illustrated as a digital signal. However, the invention is not limited to this embodiment. As noted above, the information signal **1902** can be analog, digital, and/or any combination thereof.

An oscillating signal **1904** (FIG. **19B**) is generated in step **904**. In step **906**, the oscillating signal **1904** is modulated, where the modulation is a result of, and a function of, the information signal **1902**. Step **906** produces a modulated oscillating signal **1906** (FIG. **19C**), also called a modulated intermediate signal. As noted above, the flowchart of FIG. **9** is being described in the context of an example where the information signal **1902** is a digital signal. However, alternatively, the information signal **1902** can be analog or any combination of analog and digital. Also, the example shown in FIG. **19** uses frequency shift keying (FSK) as the modulation technique. Alternatively, any modulation technique (e.g., FM, AM, PM, ASK, PSK, etc., or any combination thereof) can be used. The remaining steps **908-912** of the flowchart of FIG. **9** operate in the same way, whether the information signal **1902** is digital, analog, etc., or any combination thereof, and regardless of what modulation technique is used.

A harmonically rich signal **1908** (FIG. **19D**) is generated from the modulated signal **1906** in step **908**. Signal **1908** has a substantially continuous and periodically repeated waveform. In an embodiment, the waveform of signal **1908** is substantially rectangular, as is seen in the expanded waveform **1910** of FIG. **19E**. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent or requirement of the present invention that a perfect rectangular waveform be generated or needed. However, for ease of discussion, the term "rectangular waveform" will be used herein and will refer to waveforms that are substantially rectangular, and will include but will not be limited to those waveforms that are generally referred to as square waves or pulses. It should be noted that if the situation arises wherein a perfect rectangular waveform is proven to be both technically and mathematically feasible, that situation will also fall within the scope and intent of this invention.

A continuous periodic waveform (such as waveform **1908**) is composed of a series of sinusoidal waves of specific amplitudes and phases, the frequencies of which are integer multiples of the repetition frequency of the waveform. (A wave-

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form's repetition frequency is the number of times per second the periodic waveform repeats.) A portion of the waveform of signal **1908** is shown in an expanded view as waveform **1910** of FIG. **19E**. The first three sinusoidal components of waveform **1910** (FIG. **19E**) are depicted as waveforms **1912a, b, & c** of FIG. **19F** and waveforms **1914a, b, & c** of FIG. **19G**. (In the examples of FIGS. **19F** & **19G**, the three sinusoidal components are shown separately. In actuality, these waveforms, along with all the other sinusoidal components which are not shown, occur simultaneously, as seen in FIG. **19H**. Note that in FIG. **19H**, the waveforms are shown simultaneously, but are not shown summed. If waveforms **1912** and **1914** were shown summed, they would, in the limit, i.e., with an infinite number of sinusoidal components, be identical to the periodic waveform **1910** of FIG. **19E**. For ease of illustration, only the first three of the infinite number of sinusoidal components are shown.) These sinusoidal waves are called harmonics, and their existence can be demonstrated both graphically and mathematically. Each harmonic (waveforms **1912a, b, & c** and **1914a, b, & c**) has the same information content as does waveform **1910** (which has the same information as the corresponding portion of waveform **1908**). Accordingly, the information content of waveform **1908** can be obtained from any of its harmonics. As the harmonics have frequencies that are integer multiples of the repetition frequency of signal **1908**, and since they have the same information content as signal **1908** (as just stated), the harmonics each represent an up-converted representation of signal **1908**. Some of the harmonics are at desired frequencies (such as the frequencies desired to be transmitted). These harmonics are called "desired harmonics" or "wanted harmonics." According to the invention, desired harmonics have sufficient amplitude for accomplishing the desired processing (i.e., being transmitted). Other harmonics are not at the desired frequencies. These harmonics are called "undesired harmonics" or "unwanted harmonics."

In step **910**, any unwanted harmonics of the continuous periodic waveform of signal **1908** are filtered out (for example, any harmonics that are not at frequencies desired to be transmitted). In the example of FIG. **19**, the first and second harmonics (i.e., those depicted by waveforms **1912a & b** of FIGS. **19F** and **1914a & b** of FIG. **19G**) are the unwanted harmonics. In step **912**, the remaining harmonic, in the example of FIG. **19**, the third harmonic (i.e., those depicted by waveforms **1912c** of FIGS. **19F** and **1914c** of FIG. **19G**), is transmitted. This is depicted by waveform **1918** of FIG. **19I**. In the example of FIG. **19**, only three harmonics are shown, and the lowest two are filtered out to leave the third harmonic as the desired harmonic. In actual practice, there are an infinite number of harmonics, and the filtering can be made to remove unwanted harmonics that are both lower in frequency than the desired harmonic as well as those that are higher in frequency than the desired harmonic.

### 3.1.2 Structural Description.

FIG. **10** is a block diagram of an up-conversion system according to an embodiment of the invention. This embodiment of the up-conversion system is shown as a transmitter **1000**. Transmitter **1000** includes an acceptance module **1004**, a harmonic generation and extraction module **1006**, and a transmission module **1008** that accepts an information signal **1002** and outputs a transmitted signal **1014**.

Preferably, the acceptance module **1004**, harmonic generation and extraction module **1006**, and transmission module **1008** process the information signal in the manner shown in the operational flowchart **900**. In other words, transmitter **1000** is the structural embodiment for performing the operational steps of flowchart **900**. However, it should be under-

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stood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 900. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1000 will now be described in detail with reference to the flowchart 900. In step 902, an information signal 1002 (for example, see FIG. 19A) from a source (not shown) is routed to acceptance module 1004. In step 904, an oscillating signal (for example, see FIG. 19B) is generated and in step 906, it is modulated, thereby producing a modulated signal 1010 (for an example of FM, see FIG. 19C). The oscillating signal can be modulated using any modulation technique, examples of which are described below. In step 908, the harmonic generation and extraction module (HGEM) generates a harmonically rich signal with a continuous and periodic waveform (an example of FM can be seen in FIG. 19D). This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform. A Fourier series analysis can be used to determine the amplitude of each harmonic (for example, see FIGS. 19F and 19G). In step 910, a filter (not shown) within HGEM 1006 filters out the undesired frequencies (harmonics), and outputs an electromagnetic (EM) signal 1012 at the desired frequency (for example, see FIG. 19I). In step 912, EM signal 1012 is routed to transmission module 1008 (optional), where it is prepared for transmission. The transmission module 1008 then outputs a transmitted signal 1014.

### 3.2 Exemplary Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

#### 3.2.1 First Embodiment: Frequency Modulation (FM) Mode.

In this embodiment, an information signal is accepted and a modulated signal whose frequency varies as a function of the information signal results.

##### 3.2.1.1 Operational Description.

The flow chart of FIG. 11 demonstrates the method of operation of a transmitter in the frequency modulation (FM) mode according to an embodiment of the present invention. As stated above, the representative waveforms shown in FIG. 19 depict the invention operating as a transmitter in the FM mode.

In step 1102, an information signal 1902 (FIG. 19A) is generated by a source by any means and/or process. (Information signal 1902 is a baseband signal, and, because it is used to modulate a signal, may also be referred to as a modulating baseband signal 1902.) Information signal 1902 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 19 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with an analog information signal wherein the information is represented by a continuously varying signal. In step 1104,

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information signal 1902 modulates an oscillating signal 1904 (FIG. 19B). The result of this modulation is the modulated signal 1906 (FIG. 19C) as indicated in block 1106. Modulated signal 1906 has a frequency that varies as a function of information signal 1902 and is referred to as an FM signal.

In step 1108, a harmonically rich signal with a continuous periodic waveform, shown in FIG. 19D as rectangular waveform 1908, is generated. Rectangular waveform 1908 is generated using the modulated signal 1906. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent of the present invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed. A portion of rectangular waveform 1908 is shown in an expanded view as periodic waveform 1910 in FIG. 19E. The first part of waveform 1910 is designated "signal A" and represents information signal 1902 being "high," and the second part of waveform 1910 is designated "signal B" and information signal 1902 being "low." It should be noted that this convention is used for illustrative purposes only, and alternatively, other conventions could be used.

As stated before, a continuous and periodic waveform, such as a rectangular wave 1908 as indicated in block 1110 of flowchart 1100, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (i.e., at the Fourier component frequencies). Three harmonics of periodic waveform 1910 are shown separately, in expanded views, in FIGS. 19F and 19G. Since waveform 1910 (and also waveform 1908) is shown as a square wave in this exemplary embodiment, only the odd harmonics are present, i.e., the first, third, fifth, seventh, etc. As shown in FIG. 19, if rectangular waveform 1908 has a fundamental frequency of  $f_1$  (also known as the first harmonic), the third harmonic will have a frequency of  $3 \cdot f_1$ , the fifth harmonic will have a frequency of  $5 \cdot f_1$ , and so on. The first, third, and fifth harmonics of signal A are shown as waveforms 1912a, 1912b, and 1912c of FIG. 19F, and the first, third, and fifth harmonics of signal B are shown as waveforms 1914a, 1914b, and 1914c of FIG. 19G. In actuality, these harmonics (as well as all of the higher order harmonics) occur simultaneously, as shown by waveform 1916 of FIG. 19H. Note that if all of the harmonic components of FIG. 19H were shown summed together with all of the higher harmonics (i.e., the seventh, the ninth, etc.) the resulting waveform would, in the limit, be identical to waveform 1910.

In step 1112, the unwanted frequencies of waveform 1916 are removed. In the example of FIG. 19, the first and third harmonics are shown to be removed, and as indicated in block 1114, the remaining waveform 1918 (i.e., waveforms 1912c and 1914c) is at the desired EM frequency. Although not shown, the higher harmonics the seventh, ninth, etc.) are also removed.

The EM signal, shown here as remaining waveform 1918, is prepared for transmission in step 1116, and in step 1118, the EM signal is transmitted.

##### 3.2.1.2 Structural Description.

FIG. 12 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an FM transmitter 1200. FM transmitter 1200 includes a voltage controlled oscillator (VCO) 1204, a switch module 1214, a filter 1218, and a transmission module

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1222 that accepts an information signal 1202 and outputs a transmitted signal 1224. The operation and structure of exemplary components are described below: an exemplary VCO is described below at sections 3.3.1-3.3.1.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the voltage controlled oscillator 1204, switch module 1214, filter 1218, and transmission module 1222 process the information signal in the manner shown in the operational flowchart 1100. In other words, FM transmitter 1200 is the structural embodiment for performing the operational steps of flowchart 1100. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1100. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1200 will now be described in detail with reference to the flowchart 1100. In step 1102, an information signal 1202 (for example, see FIG. 19A) from a source (not shown) is routed to VCO 1204. In step 1104, an oscillating signal (for example, see FIG. 19B) is generated and modulated, thereby producing a frequency modulated signal 1210 (for example, see FIG. 19C). In step 1108, the switch module 1214 generates a harmonically rich signal 1216 with a continuous and periodic waveform (for example, see FIG. 19D). This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform, and a Fourier analysis will determine the amplitude of each harmonic (for example, see FIGs. 19F and 19G). In step 1112, a filter 1218 filters out the undesired frequencies (harmonics), and outputs an electromagnetic (EM) signal 1220 at the desired harmonic frequency (for example, see FIG. 19I). In step 1116, EM signal 1220 is routed to transmission module 1222 (optional), where it is prepared for transmission. In step 1118, transmission module 1222 outputs a transmitted signal 1224.

#### 3.2.2 Second Embodiment: Phase Modulation (PM) Mode.

in this embodiment, an information signal is accepted and a modulated signal whose phase varies as a function of the information signal is transmitted.

##### 3.2.2.1 Operational Description.

The flow chart of FIG. 13 demonstrates the method of operation of the transmitter in the phase modulation (PM) mode. The representative waveforms shown in FIG. 44 depict the invention operating as a transmitter in the PM mode.

In step 1302, an information signal 4402 (FIG. 44A) is generated by a source. Information signal 4402 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 44 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with an analog information signal wherein the information is represented by a continuously varying signal. In step 1304, an oscillating signal 4404 is generated and in step 1306, the oscillating signal 4404 (FIG. 44B) is modulated by the information signal 4402, resulting in the modulated signal 4406 (FIG. 44C) as indicated in block 1308. The phase of this modulated signal 4406 is varied as a function of the information signal 4402.

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A harmonically rich signal 4408 (FIG. 44D) with a continuous periodic waveform is generated at step 1310 using modulated signal 4406. Harmonically rich signal 4408 is a substantially rectangular waveform. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent of the present invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed. As stated before, a continuous and periodic waveform, such as the harmonically rich signal 4408 as indicated in block 1312, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). The first three harmonic waveforms are shown in FIGs. 44E, 44F, and 44G. In actual fact, there are an infinite number of harmonics. In step 1314, the unwanted frequencies are removed, and as indicated in block 1316, the remaining frequency is at the desired EM output. As an example, the first (fundamental) harmonic 4410 and the second harmonic 4412 along with the fourth, fifth, etc., harmonics (not shown) might be filtered out, leaving the third harmonic 4414 as the desired EM signal as indicated in block 1316.

The EM signal is prepared for transmission in step 1318, and in step 1320, the EM signal is transmitted.

##### 3.2.2.2 Structural Description.

FIG. 14 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as a PM transmitter 1400. PM transmitter 1400 includes a local oscillator 1406, a phase modulator 1404, a switch module 1410, a filter 1414, and a transmission module 1418 that accepts an information signal 1402 and outputs a transmitted signal 1420. The operation and structure of exemplary components are described below: an exemplary phase modulator is described below at sections 3.3.4-3.3.4.2; an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1406, phase modulator 1404, switch module 1410, filter 1414, and transmission module 1418 process the information signal in the manner shown in the operational flowchart 1300. In other words, PM transmitter 1400 is the structural embodiment for performing the operational steps of flowchart 1300. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1300. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1400 will now be described in detail with reference to the flowchart 1300. In step 1302, an information signal 1402 (for example, see FIG. 44A) from a source (not shown) is routed to phase modulator 1404. In step 1304, an oscillating signal from local oscillator 1406 (for example, see FIG. 44B) is generated and modulated, thereby producing a modulated signal 1408 (for example, see FIG. 44C). In step 1310, the switch module 1410 generates a harmonically rich signal 1412 with a continuous and periodic waveform (for example, see FIG. 44D).

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This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform, and a Fourier analysis will determine the amplitude of each harmonic (for an example of the first three harmonics, see FIGS. 44E, 44F, and 44G). In step 1314, a filter 1414 filters out the undesired harmonic frequencies (for example, the first harmonic 4410, the second harmonic 4412, and the fourth, fifth, etc., harmonics, not shown), and outputs an electromagnetic (EM) signal 1416 at the desired harmonic frequency (for example, the third harmonic, see FIG. 44G). In step 1318, EM signal 1416 is routed to transmission module 1418 (optional), where it is prepared for transmission. In step 1320, the transmission module 1418 outputs a transmitted signal 1420.

### 3.2.3 Third Embodiment: Amplitude Modulation (AM) Mode.

In this embodiment, an information signal is accepted and a modulated signal whose amplitude varies as a function of the information signal is transmitted.

#### 3.2.3.1 Operational Description.

The flow chart of FIG. 15 demonstrates the method of operation of the transmitter in the amplitude modulation (AM) mode. The representative waveforms shown in FIG. 45 depict the invention operating as a transmitter in the AM mode.

In step 1502, an information signal 4502 (FIG. 45A) is generated by a source. Information signal 4502 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 45 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with an analog information signal wherein the information is represented by a continuously varying signal. In step 1504, a "reference signal" is created, which, as indicated in block 1506, has an amplitude that is a function of the information signal 4502. In one embodiment of the invention, the reference signal is created by combining the information signal 4502 with a bias signal. In another embodiment of the invention, the reference signal is comprised of only the information signal 4502. One skilled in the relevant art(s) will recognize that any number of embodiments exist wherein the reference signal will vary as a function of the information signal.

An oscillating signal 4504 (FIG. 45B) is generated at step 1508, and at step 1510, the reference signal (information signal 4502) is gated at a frequency that is a function of the oscillating signal 4504. The gated referenced signal is a harmonically rich signal 4506 (FIG. 45C) with a continuous periodic waveform and is generated at step 1512. This harmonically rich signal 4506 as indicated in block 1514 is substantially a rectangular wave which has a fundamental frequency equal to the frequency at which the reference signal (information signal 4502) is gated. In addition, the rectangular wave has pulse amplitudes that are a function of the amplitude of the reference signal (information signal 4502). One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent of the present invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those

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waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed.

As stated before, a harmonically rich signal 4506, such as the rectangular wave as indicated in block 1514, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). The first three harmonic waveforms are shown in FIGS. 45D, 45E, and 45F. In fact, there are an infinite number of harmonics. In step 1516, the unwanted frequencies are removed, and as indicated in block 1518, the remaining frequency is at the desired EM output. As an example, the first (fundamental) harmonic 4510 and the second harmonic 4512 along with the fourth, fifth, etc., harmonics (not shown) might be filtered out leaving the third harmonic 4514 as the desired EM signal as indicated in block 1518.

The EM signal is prepared for transmission in step 1520, and in step 1522, the EM signal is transmitted.

#### 3.2.3.2 Structural Description.

FIG. 16 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an AM transmitter 1600. AM transmitter 1600 includes a local oscillator 1610, a summing module 1606, a switch module 1614, a filter 1618, and a transmission module 1622 that accepts an information signal 1602 and outputs a transmitted signal 1624. The operation and structure of exemplary components are described below: an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary switch module is described below at sections 3.3.7-3.3.7.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1610, summing module 1606, switch module 1614, filter 1618, and transmission module 1622 process an information signal 1602 in the manner shown in the operational flowchart 1500. In other words, AM transmitter 1600 is the structural embodiment for performing the operational steps of flowchart 1500. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1500. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1600 will now be described in detail with reference to the flowchart 1500. In step 1502, information signal 1602 (for example, see FIG. 45A) from a source (not shown) is routed to summing module 1606 (if required), thereby producing a reference signal 1608. In step 1508, an oscillating signal 1612 is generated by local oscillator 1610 (for example, see FIG. 45B) and in step 1510, switch module 1614 gates the reference voltage 1608 at a rate that is a function of the oscillating signal 1612. The result of the gating is a harmonically rich signal 1616 (for example, see FIG. 45C) with a continuous and periodic waveform. This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform, and a Fourier analysis will determine the relative amplitude of each harmonic (for an example of the first three harmonics, see FIGS. 45D, 45E, and 45F). When amplitude modulation is applied, the amplitude of the pulses in rectangular waveform 1616 vary as a function of reference signal 1608. As a result, this change in amplitude of the pulses has a propor-

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tional effect on the absolute amplitude of all of the harmonics. In other words, the AM is embedded on top of each of the harmonics. In step 1516, a filter 1618 filters out the undesired harmonic frequencies (for example, the first harmonic 4510, the second harmonic 4512, and the fourth, fifth, etc., harmonics, not shown), and outputs an electromagnetic (EM) signal 1620 at the desired harmonic frequency (for example, the third harmonic, see FIG. 45F). In step 1520, EM signal 1620 is routed to transmission module 1622 (optional), where it is prepared for transmission. In step 1522, the transmission module 1622 outputs a transmitted signal 1624.

Note that the description of the AM embodiment given herein shows the information signal being gated, thus applying the amplitude modulation to the harmonically rich signal. However, it would be apparent based on the teachings contained herein, that the information signal can be modulated onto the harmonically rich signal or onto a filtered harmonic at any point in the circuit.

#### 3.2.4 Fourth Embodiment: In-Phase/Quadrature-Phase Modulation ("I/Q") Mode.

In-phase/quadrature-phase modulation ("I/Q") is a specific subset of a phase modulation (PM) embodiment. Because "I/Q" is so pervasive, it is described herein as a separate embodiment. However, it should be remembered that since it is a specific subset of PM, the characteristics of PM also apply to "I/Q."

In this embodiment, two information signals are accepted. An in-phase signal ("I") is modulated such that its phase varies as a function of one of the information signals, and a quadrature-phase signal ("Q") is modulated such that its phase varies as a function of the other information signal. The two modulated signals are combined to form an "I/Q" modulated signal and transmitted.

##### 3.2.4.1 Operational Description.

The flow chart of FIG. 17 demonstrates the method of operation of the transmitter in the in-phase/quadrature-phase modulation ("I/Q") mode. In step 1702, a first information signal is generated by a first source. This information signal may be analog, digital, or any combination thereof. In step 1710, an in-phase oscillating signal (referred to as the "I" signal) is generated and in step 1704, it is modulated by the first information signal. This results in the "I" modulated signal as indicated in block 1706 wherein the phase of the "I" modulated signal is varied as a function of the first information signal.

In step 1714, a second information signal is generated. Again, this signal may be analog, digital, or any combination thereof, and may be different than the first information signal. In step 1712, the phase of "I" oscillating signal generated in step 1710 is shifted, creating a quadrature-phase oscillating signal (referred to as the "Q" signal). In step 1716, the "Q" signal is modulated by the second information signal. This results in the "Q" modulated signal as indicated in block 1718 wherein the phase of the "Q" modulated signal is varied as a function of the second information signal.

An "I" signal with a continuous periodic waveform is generated at step 1708 using the "I" modulated signal, and a "Q" signal with a continuous periodic waveform is generated at step 1720 using the "Q" modulated signal. In step 1722, the "I" periodic waveform and the "Q" periodic waveform are combined forming what is referred to as the "I/Q" periodic waveform as indicated in block 1724. As stated before, a continuous and periodic waveform, such as a "I/Q" rectangular wave as indicated in block 1724, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). In step 1726, the unwanted

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frequencies are removed, and as indicated in block 1728, the remaining frequency is at the desired EM output.

The "I/Q" EM signal is prepared for transmission in step 1730, and in step 1732, the "I/Q" EM signal is transmitted.

##### 3.2.4.2 Structural Description.

FIG. 18 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an "I/Q" transmitter 1800. "I/Q" transmitter 1800 includes a local oscillator 1806, a phase shifter 1810, two phase modulators 1804 & 1816, two switch modules 1822 & 1828, a summer 1832, a filter 1836, and a transmission module 1840. The "I/Q" transmitter accepts two information signals 1802 & 1814 and outputs a transmitted signal 1420. The operation and structure of exemplary components are described below: an exemplary phase modulator is described below at sections 3.3.4-3.3.4.2; an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary phase shifter is described below at sections 3.3.3-3.3.3.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary summer is described below at sections 3.3.8-3.3.8.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1806, phase shifter 1810, phase modulators 1804 & 1816, switch modules 1822 & 1828, summer 1832, filter 1836, and transmission module 1840 process the information signal in the manner shown in the operational flowchart 1700. In other words, "I/Q" transmitter 1800 is the structural embodiment for performing the operational steps of flowchart 1700. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1700. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1800 will now be described in detail with reference to the flowchart 1700. In step 1702, a first information signal 1802 from a source (not shown) is routed to the first phase modulator 1804. In step 1710, an "I" oscillating signal 1808 from local oscillator 1806 is generated and in step 1704, "I" oscillating signal 1808 is modulated by first information signal 1802 in the first phase modulator 1804, thereby producing an "I" modulated signal 1820. In step 1708, the first switch module 1822 generates a harmonically rich "I" signal 1824 with a continuous and periodic waveform.

In step 1714, a second information signal 1814 from a source (not shown) is routed to the second phase modulator 1816. In step 1712, the phase of oscillating signal 1808 is shifted by phase shifter 1810 to create "Q" oscillating signal 1812. In step 1716, "Q" oscillating signal 1812 is modulated by second information signal 1814 in the second phase modulator 1816, thereby producing "Q" modulated signal 1826. In step 1720, the second switch module 1828 generates a harmonically rich "Q" signal 1830 with a continuous and periodic waveform. Harmonically rich "I" signal 1824 and harmonically rich "Q" signal 1830 are preferably rectangular waves, such as square waves or pulses (although, the invention is not limited to this embodiment), and are comprised of pluralities of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveforms. These sinusoidal waves are referred to as the harmonics of the underlying waveforms, and a Fourier analysis will determine the amplitude of each harmonic.

In step 1722, harmonically rich "I" signal 1824 and harmonically rich "Q" signal 1830 are combined by summer

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1832 to create harmonically rich “I/Q” signal 1834. In step 1726, a filter 1836 filters out the undesired harmonic frequencies, and outputs an “I/Q” electromagnetic (EM) signal 1838 at the desired harmonic frequency. In step 1730, “I/Q” EM signal 1838 is routed to transmission module 1840 (optional), where it is prepared for transmission. In step 1732, the transmission module 1840 outputs a transmitted signal 1842.

it will be apparent to those skilled in the relevant art(s) that an alternate embodiment exists wherein the harmonically rich “I” signal 1824 and the harmonically rich “Q” signal 1830 may be filtered before they are summed, and further, another alternate embodiment exists wherein “I” modulated signal 1820 and “Q” modulated signal 1826 may be summed to create an “I/Q” modulated signal before being routed to a switch module.

### 3.2.5 Other Embodiments.

Other embodiments of the up-converter of the present invention being used as a transmitter (or in other applications) may use subsets and combinations of modulation techniques. These would be apparent to one skilled in the relevant art(s) based on the teachings disclosed herein, and include, but are not limited to, quadrature amplitude modulation (QAM), and embedding two forms of modulation onto a signal for up-conversion.

An exemplary circuit diagram illustrating the combination of two modulations is found in FIG. 62. This example uses AM combined with PM. The waveforms shown in FIG. 63 illustrate the phase modulation of a digital information signal “A” 6202 combined with the amplitude modulation of an analog information signal “B” 6204. An oscillating signal 6216 (FIG. 63B) and information signal “A” 6202 (FIG. 63A) are received by phase modulator 1404, thereby creating a phase modulated signal 6208 (FIG. 63C). Note that for illustrative purposes, and not limiting, the information signal is shown as a digital signal, and the phase modulation is shown as shifting the phase of the oscillating signal by 180°. Those skilled in the relevant art(s) will appreciate that the information signal could be analog (although typically it is digital), and that phase modulations other than 180° may also be used. FIG. 62 shows a pulse shaper 6216 receiving phase modulated signal 6208 and outputting a pulse-shaped PM signal 6210. The pulse shaper is optional, depending on the selection and design of the phase modulator 1404. Information signal “B” 6304 and bias signal 1604 (if required) are combined by summing module 1606 (optional) to create reference signal 6206 (FIG. 63E). Pulse-shaped PM signal 6210 is routed to switch module 1410, 1614 where it gates the reference signal 6206 thereby producing a harmonically rich signal 6212 (FIG. 63F). It can be seen that the amplitude of harmonically rich signal 6212 varies as a function of reference signal 6206, and the period and pulse width of harmonically rich signal 6212 are substantially the same as pulse-shaped PM signal 6210. FIG. 63 only illustrates the fundamental and second harmonics of harmonically rich signal 6212. In fact, there may be an infinite number of harmonics, but for illustrative purposes (and not limiting) the first two harmonics are sufficient to illustrate that both the phase modulation and the amplitude modulation that are present on the harmonically rich signal 6212 are also present on each of the harmonics. Filter 1414, 1618 will remove the unwanted harmonics, and a desired harmonic 6214 is routed to transmission module 1418, 1622 (optional) where it is prepared for transmission. Transmission module 1418, 1622 then outputs a transmitted signal 1420, 1624. Those skilled in the relevant art(s) will appreciate that these examples are provided for illustrative purposes only and are not limiting.

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The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments include, but are not limited to, combinations of modulation techniques in an “I/Q” mode. Such alternate embodiments fall within the scope and spirit of the present invention.

### 3.3 Methods and Systems for Implementing the Embodiments.

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

#### 3.3.1 The Voltage Controlled Oscillator (FM Mode).

As discussed above, the frequency modulation (FM) mode embodiment of the invention uses a voltage controlled oscillator (VCO). See, as an example, VCO 1204 in FIG. 12. The invention supports numerous embodiments of the VCO. Exemplary embodiments of the VCO 2304 (FIG. 23) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

##### 3.3.1.1 Operational Description.

The information signal 2302 is accepted and an oscillating signal 2306 whose frequency varies as a function of the information signal 2302 is created. Oscillating signal 2306 is also referred to as frequency modulated intermediate signal 2306. The information signal 2302 may be analog or digital or a combination thereof, and may be conditioned to ensure it is within the desired range.

In the case where the information signal 2302 is digital, the oscillating signal 2306 may vary between discrete frequencies. For example, in a binary system, a first frequency corresponds to a digital “high,” and a second frequency corresponds to a digital “low.” Either frequency may correspond to the “high” or the “low,” depending on the convention being used. This operation is referred to as frequency shift keying (FSK) which is a subset of FM. If the information signal 2302 is analog, the frequency of the oscillating signal 2306 will vary as a function of that analog signal, and is not limited to the subset of FSK described above.

The oscillating signal 2306 is a frequency modulated signal which can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term “rectangular waveform” will be used to refer to waveforms that are substantially rectangular, the term “square wave” will refer to those waveforms that are substantially square, the term “triangular wave” will refer to those waveforms that are substantially triangular, and the term “pulse” will refer to those waveforms that are substan-

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tially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

### 3.3.1.2 Structural Description.

The design and use of a voltage controlled oscillator **2304** is well known to those skilled in the relevant art(s). The VCO **2304** may be designed and fabricated from discrete components, or it may be purchased "off the shelf." VCO **2304** accepts an information signal **2302** from a source. The information signal **2302** is at baseband and generally is an electrical signal within a prescribed voltage range. If the information is digital, the voltage will be at discrete levels. If the information is analog, the voltage will be continuously variable between an upper and a lower level. The VCO **2304** uses the voltage of the information signal **2302** to cause a modulated oscillating signal **2306** to be output. The information signal **2302**, because it is a baseband signal and is used to modulate the oscillating signal, may be referred to as the modulating baseband signal **2302**.

The frequency of the oscillating signal **2306** varies as a function of the voltage of the modulating baseband signal **2302**. If the modulating baseband signal **2302** represents digital information, the frequency of the oscillating signal **2306** will be at discrete levels. If, on the other hand, the modulating baseband signal **2302** represents analog information, the frequency of the oscillating signal **2306** will be continuously variable between its higher and lower frequency limits. The oscillating signal **2306** can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The frequency modulated oscillating signal **2306** may then be used to drive a switch module **2802**.

### 3.3.2 The Local Oscillator (PM, AM, and "I/Q" Modes).

As discussed above, the phase modulation (PM) and amplitude modulation (AM) mode embodiments of the invention use a local oscillator. So too does the in-phase/quadrature-phase modulation ("I/Q") mode embodiment. See, as an example, local oscillator **1406** in FIG. **14**, local oscillator **1610** in FIG. **16**, and local oscillator **1806** in FIG. **18**. The invention supports numerous embodiments of the local oscillator. Exemplary embodiments of the local oscillator **2402** (FIG. **24**) are described below.

However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

### 3.3.2.1 Operational Description.

An oscillating signal **2404** is generated. The frequency of the signal **2404** may be selectable, but generally is not considered to be "variable." That is, the frequency may be selected to be a specific value for a specific implementation, but generally it does not vary as a function of the information signal **2302** (i.e., the modulating baseband signal).

The oscillating signal **2404** generally is a sinusoidal wave, but it may also be a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse,

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and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

### 3.3.2.2 Structural Description.

The design and use of a local oscillator **2402** is well known to those skilled in the relevant art(s). A local oscillator **2402** may be designed and fabricated from discrete components or it may be purchased "off the shelf." A local oscillator **2402** is generally set to output a specific frequency. The output can be "fixed" or it can be "selectable," based on the design of the circuit. If it is fixed, the output is considered to be substantially a fixed frequency that cannot be changed. If the output frequency is selectable, the design of the circuit will allow a control signal to be applied to the local oscillator **2402** to change the frequency for different applications. However, the output frequency of a local oscillator **2402** is not considered to be "variable" as a function of an information signal **2302** such as the modulating baseband signal **2302**. (If it were desired for the output frequency of an oscillator to be variable as a function of an information signal, a VCO would preferably be used.) The oscillating signal **2404** generally is a sinusoidal wave, but it may also be a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The output of a local oscillator **2402** may be an input to other circuit components such as a phase modulator **2606**, a phase shifting circuit **2504**, switch module **3102**, etc.

### 3.3.3 The Phase Shifter ("I/Q" Mode).

As discussed above, the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a phase shifter. See, as an example, phase shifter **1810** in FIG. **18**. The invention supports numerous embodiments of the phase shifter. Exemplary embodiments of the phase shifter **2504** (FIG. **25**) are described below. The invention is not limited to these embodiments. The description contained herein is for a "90° phase shifter." The 90° phase shifter is used for ease of explanation, and one skilled in the relevant art(s) will understand that other phase shifts can be used without departing from the intent of the present invention.

### 3.3.3.1 Operational Description.

An "in-phase" oscillating signal **2502** is received and a "quadrature-phase" oscillating signal **2506** is output. If the in-phase ("I") signal **2502** is referred to as being a sine wave, then the quadrature-phase ("Q") signal **2506** can be referred to as being a cosine wave (i.e., the "Q" signal **2506** is 90° out of phase with the "I" signal **2502**). However, they may also be rectangular waves, triangular waves, pulses, or any other continuous and periodic waveforms. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed. Regardless of the shapes of the waveforms, the "Q" signal **2506** is out of phase with the "I" signal **2502** by one-quarter period of the waveform. The frequency of the "I" and "Q" signals **2502** and **2506** are substantially equal.

The discussion contained herein will be confined to the more prevalent embodiment wherein there are two intermediate signals separated by 90°. This is not limiting on the

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invention. It will be apparent to those skilled in the relevant art(s) that the techniques taught herein and applied to the "I/Q" embodiment of the present invention also apply to more exotic embodiments wherein the intermediate signals are shifted by some amount other than  $90^\circ$ , and also wherein there may be more than two intermediate frequencies.

### 3.3.3.2 Structural Description.

The design and use of a phase shifter **2504** is well known to those skilled in the relevant art(s). A phase shifter **2504** may be designed and fabricated from discrete components or it may be purchased "off the shelf." A phase shifter accepts an "in-phase" ("I") oscillating signal **2502** from any of a number of sources, such as a VCO **2304** or a local oscillator **2402**, and outputs a "quadrature-phase" ("Q") oscillating signal **2506** that is substantially the same frequency and substantially the same shape as the incoming "I" signal **2502**, but with the phase shifted by  $90^\circ$ . Both the "I" and "Q" signals **2502** and **2506** are generally sinusoidal waves, but they may also be rectangular waves, triangular waves, pulses, or any other continuous and periodic waveforms. Regardless of the shapes of the waveforms, the "Q" signal **2506** is out of phase with the "I" signal **2502** by one-quarter period of the waveform. Both the "I" and "Q" signals **2502** and **2506** may be modulated.

The output of a phase shifter **2504** may be used as an input to a phase modulator **2606**.

### 3.3.4 The Phase Modulator (PM and "I/Q" Modes).

As discussed above, the phase modulation (PM) mode embodiment including the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a phase modulator. See, as an example, phase modulator **1404** of FIG. **14** and phase modulators **1804** and **1816** of FIG. **18**. The invention supports numerous embodiments of the phase modulator. Exemplary embodiments of the phase modulator **2606** (FIG. **26**) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### 3.3.4.1 Operational Description.

An information signal **2602** and an oscillating signal **2604** are accepted, and a phase modulated oscillating signal **2608** whose phase varies as a function of the information signal **2602** is output. The information signal **2602** may be analog or digital and may be conditioned to ensure it is within the desired range. The oscillating signal **2604** can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed. The modulated oscillating signal **2608** is also referred to as the modulated intermediate signal **2608**.

In the case where the information signal **2602** is digital, the modulated intermediate signal **2608** will shift phase between discrete values, the first phase (e.g., for a signal represented by  $\sin(\omega t + \theta_0)$ ) corresponding to a digital "high," and the second phase (e.g., for a signal represented by  $\sin(\omega t + \theta_0 + \delta)$ ), where  $\delta$  represents the amount the phase has been shifted)

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corresponding to a digital "low." Either phase may correspond to the "high" or the "low," depending on the convention being used. This operation is referred to as phase shift keying (PSK) which is a subset of PM.

If the information signal **2602** is analog, the phase of the modulated intermediate signal **2608** will vary as a function of the information signal **2602** and is not limited to the subset of PSK described above.

The modulated intermediate signal **2608** is a phase modulated signal which can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform, and which has substantially the same period as the oscillating signal **2604**.

### 3.3.4.2 Structural Description.

The design and use of a phase modulator **2606** is well known to those skilled in the relevant art(s). A phase modulator **2606** may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A phase modulator **2606** accepts an information signal **2602** from a source and an oscillating signal **2604** from a local oscillator **2402** or a phase shifter **2504**. The information signal **2602** is at baseband and is generally an electrical signal within a prescribed voltage range. If the information is digital, the voltage will be at discrete levels. If the information is analog, the voltage will be continuously variable between an upper and a lower level as a function of the information signal **2602**. The phase modulator **2606** uses the voltage of the information signal **2602** to modulate the oscillating signal **2604** and causes a modulated intermediate signal **2608** to be output. The information signal **2602**, because it is a baseband signal and is used to modulate the oscillating signal, may be referred to as the modulating baseband signal **2604**.

The modulated intermediate signal **2608** is an oscillating signal whose phase varies as a function of the voltage of the modulating baseband signal **2602**. If the modulating baseband signal **2602** represents digital information, the phase of the modulated intermediate signal **2608** will shift by a discrete amount (e.g., the modulated intermediate signal **2608** will shift by an amount  $\delta$  between  $\sin(\omega t + \theta_0)$  and  $\sin(\omega t + \theta_0 + \delta)$ ). If, on the other hand, the modulating baseband signal **2602** represents analog information, the phase of the modulated intermediate signal **2608** will continuously shift between its higher and lower phase limits as a function of the information signal **2602**. In one exemplary embodiment, the upper and lower limits of the modulated intermediate signal **2608** can be represented as  $\sin(\omega t + \theta_0)$  and  $\sin(\omega t + \theta_0 + \pi)$ . In other embodiments, the range of the phase shift may be less than  $\pi$ . The modulated intermediate signal **2608** can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The phase modulated intermediate signal **2608** may then be used to drive a switch module **2802**.

### 3.3.5 The Summing Module (AM Mode).

As discussed above, the amplitude modulation (AM) mode embodiment of the invention uses a summing module. See, as an example, summing module **1606** in FIG. **16**. The invention supports numerous embodiments of the summing module. Exemplary embodiments of the summing module **2706** (FIG. **27**) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. It may also be used in the "I/Q" mode embodiment when the modulation is AM. The summing module **2706** need not be used in all AM embodiments.

#### 3.3.5.1 Operational Description.

An information signal **2702** and a bias signal **2702** are accepted, and a reference signal is output. The information

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signal 2702 may be analog or digital and may be conditioned to ensure it is within the proper range so as not to damage any of the circuit components. The bias signal 2704 is usually a direct current (DC) signal.

In the case where the information signal 2702 is digital, the reference signal 2706 shifts between discrete values, the first value corresponding to a digital "high," and the second value corresponding to a digital "low." Either value may correspond to the "high" or the "low," depending on the convention being used. This operation is referred to as amplitude shift keying (ASK) which is a subset of AM.

If the information signal 2702 is analog, the value of the reference signal 2708 will vary linearly between upper and lower extremes which correspond to the upper and lower limits of the information signal 2702. Again, either extreme of the reference signal 2708 range may correspond to the upper or lower limit of the information signal 2702 depending on the convention being used.

The reference signal 2708 is a digital or analog signal and is substantially proportional to the information signal 2702.

### 3.3.5.2 Structural Description.

The design and use of a summing module 2706 is well known to those skilled in the relevant art(s). A summing module 2706 may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A summing module 2706 accepts an information signal 2702 from a source. The information signal 2702 is at baseband and generally is an electrical signal within a prescribed voltage range. If the information is digital, the information signal 2702 is at either of two discrete levels. If the information is analog, the information signal 2702 is continuously variable between an upper and a lower level. The summing module 2706 uses the voltage of the information signal 2702 and combines it with a bias signal 2704. The output of the summing module 2706 is called the reference signal 2708. The purpose of the summing module 2706 is to cause the reference signal 2708 to be within a desired signal range. One skilled in the relevant art(s) will recognize that the information signal 2702 may be used directly, without being summed with a bias signal 2704, if it is already within the desired range. The information signal 2702 is a baseband signal, but typically, in an AM embodiment, it is not used to directly modulate an oscillating signal. The amplitude of the reference signal 2708 is at discrete levels if the information signal 2702 represents digital information. On the other hand, the amplitude of the reference signal 2708 is continuously variable between its higher and lower limits if the information signal 2702 represents analog information. The amplitude of the reference signal 2708 is substantially proportional to the information signal 2702, however, a positive reference signal 2708 need not represent a positive information signal 2702.

The reference signal 2708 is routed to the first input 3108 of a switch module 3102. In one exemplary embodiment, a resistor 2824 is connected between the output of the summing module 2706 (or the source of the information signal 2702 in the embodiment wherein the summing amplifier 2706 is not used) and the switch 3116 of the switch module 3102.

### 3.3.6 The Switch Module (FM, PM, and "I/Q" Modes).

As discussed above, the frequency modulation (FM), phase modulation (PM), and the in-phase/quadrature-phase modulation ("I/Q") mode embodiments of the invention use a switching assembly referred to as switch module 2802 (FIGS. 28A-28C). As an example, switch module 2802 is a component in switch module 1214 in FIG. 12, switch module 1410 in FIG. 14, and switch modules 1822 and 1828 in FIG. 18. The invention supports numerous embodiments of the switch module. Exemplary embodiments of the switch module 2802

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are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. The switch module 2802 and its operation in the FM, PM, and "I/Q" mode embodiments is substantially the same as its operation in the AM mode embodiment, described in sections 3.3.7-3.3.7.2 below.

### 3.3.6.1 Operational Description.

A bias signal 2806 is gated as a result of the application of a modulated oscillating signal 2804, and a signal with a harmonically rich waveform 2814 is created. The bias signal 2806 is generally a fixed voltage. The modulated oscillating signal 2804 can be frequency modulated, phase modulated, or any other modulation scheme or combination thereof. In certain embodiments, such as in certain amplitude shift keying modes, the modulated oscillating signal 2804 may also be amplitude modulated. The modulated oscillating signal 2804 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, modulated oscillating signal 2804 would be a rectangular wave. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

The signal with harmonically rich waveform 2814, hereafter referred to as the harmonically rich signal 2814, is a continuous and periodic waveform that is modulated substantially the same as the modulated oscillating signal 2804. That is, if the modulated oscillating signal 2804 is frequency modulated, the harmonically rich signal 2814 will also be frequency modulated, and if the modulated oscillating signal 2804 is phase modulated, the harmonically rich signal 2814 will also be phase modulated. (In one embodiment, the harmonically rich signal 2814 is a substantially rectangular waveform.) As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich signal 2814 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself.

### 3.3.6.2 Structural Description.

The switch module 2802 of an embodiment of the present invention is comprised of a first input 2808, a second input 2810, a control input 2820, an output 2822, and a switch 2816. A bias signal 2806 is applied to the first input 2808 of the switch module 2802. Generally, the bias signal 2806 is a fixed voltage, and in one embodiment of the invention, a resistor 2824 is located between the bias signal 2806 and the switch 2816. The second input 2810 of the switch module 2802 is generally at electrical ground 2812. However, one skilled in the relevant art(s) will recognize that alternative embodiments exist wherein the second input 2810 may not be at electrical ground 2812, but rather a second signal 2818, provided that the second signal 2818 is different than the bias signal 2806.

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A modulated oscillating signal **2804** is connected to the control input **2820** of the switch module **2802**. The modulated oscillating signal **2804** may be frequency modulated or phase modulated. (In some circumstances and embodiments, it may be amplitude modulated, such as in on/off keying, but this is not the general case, and will not be described herein.) The modulated oscillating signal **2804** can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. The modulated oscillating signal **2804** causes the switch **2816** to close and open.

The harmonically rich signal **2814** described in section 3.3.6.1 above, is found at the output **2822** of the switch module **2802**. The harmonically rich signal **2814** is a continuous and periodic waveform that is modulated substantially the same as the modulated oscillating signal **2804**. That is, if the modulated oscillating signal **2804** is frequency modulated, the harmonically rich signal **2814** will also be frequency modulated, and if the modulated oscillating signal **2804** is phase modulated, the harmonically rich signal **2814** will also be phase modulated. In one embodiment, the harmonically rich signal **2814** has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich signal **2814** is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. Each of these sinusoidal signals is also modulated substantially the same as the continuous and periodic waveform (i.e., the modulated oscillating signal **2804**) from which it is derived.

The switch module **2802** operates as follows. When the switch **2816** is "open," the output **2822** of switch module **2802** is at substantially the same voltage level as bias signal **2806**. Thus, since the harmonically rich signal **2814** is connected directly to the output **2822** of switch module **2802**, the amplitude of harmonically rich signal **2814** is equal to the amplitude of the bias signal **2806**. When the modulated oscillating signal **2804** causes the switch **2816** to become "closed," the output **2822** of switch module **2802** becomes connected electrically to the second input **2810** of switch module **2802** (e.g., ground **2812** in one embodiment of the invention), and the amplitude of the harmonically rich signal **2814** becomes equal to the potential present at the second input **2810** (e.g., zero volts for the embodiment wherein the second input **2810** is connected to electrical ground **2812**). When the modulated oscillating signal **2804** causes the switch **2816** to again become "open," the amplitude of the harmonically rich signal **2814** again becomes equal to the bias signal **2806**. Thus, the amplitude of the harmonically rich signal **2814** is at either of two signal levels, i.e., bias signal **2806** or ground **2812**, and has a frequency that is substantially equal to the frequency of the modulated oscillating signal **2804** that causes the switch **2816** to open and close. The harmonically rich signal **2814** is modulated substantially the same as the modulated oscillating signal **2804**. One skilled in the relevant art(s) will recognize that any one of a number of switch designs will fulfill the scope and spirit of the present invention as described herein.

In an embodiment of the invention, the switch **2816** is a semiconductor device, such as a diode ring. In another embodiment, the switch is a transistor, such as a field effect transistor (FET). In an embodiment wherein the FET is gallium arsenide (GaAs), switch module **2802** can be designed as seen in FIGS. 29A-29C, where the modulated oscillating signal **2804** is connected to the gate **2902** of the GaAsFET **2901**, the bias signal **2806** is connected through a bias resistor

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**2824** to the source **2904** of the GaAsFET **2901**, and electrical ground **2812** is connected to the drain **2906** of GaAsFET **2901**. (In an alternate embodiment shown in FIG. 29C, a second signal **2818** may be connected to the drain **2906** of GaAsFET **2901**.) Since the drain and the source of GaAsFETs are interchangeable, the bias signal **2806** can be applied to either the source **2904** or to the drain **2906**. If there is concern that there might be some source-drain asymmetry in the GaAsFET, the switch module can be designed as shown in FIGS. 30A-30C, wherein two GaAsFETs **3002** and **3004** are connected together, with the source **3010** of the first **3002** connected to the drain **3012** of the second **3004**, and the drain **3006** of the first **3002** being connected to the source **3008** of the second **3004**. This design arrangement will balance substantially all asymmetries. Other switch designs and implementations will be apparent to persons skilled in the relevant art(s).

The output **2822** of the switch module **2802**, i.e., the harmonically rich signal **2814**, can be routed to a filter **3504** in the FM and PM modes or to a Summer **3402** in the "I/Q" mode.

### 3.3.7 The Switch Module (AM Mode).

As discussed above, the amplitude modulation (AM) mode embodiment of the invention uses a switching assembly referred to as switch module **3102** (FIGS. 31A-31C). As an example, switch module **3102** is a component in switch module **1614** of FIG. 16. The invention supports numerous embodiments of the switch module. Exemplary embodiments of the switch module **3102** are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. The switch module **3102** and its operation in the AM mode embodiment is substantially the same as its operation in the FM, PM, and "I/Q" mode embodiments described in sections 3.3.6-3.3.6.2 above.

#### 3.3.7.1 Operational Description.

A reference signal **3106** is gated as a result of the application of an oscillating signal **3104**, and a signal with a harmonically rich waveform **3114** is created. The reference signal **3106** is a function of the information signal **2702** and may, for example, be either the summation of the information signal **2702** with a bias signal **2704** or it may be the information signal **2702** by itself. In the AM mode, the oscillating signal **3104** is generally not modulated, but can be.

The oscillating signal **3104** can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

The signal with a harmonically rich waveform **3114**, hereafter referred to as the harmonically rich signal **3114**, is a continuous and periodic waveform whose amplitude is a function of the reference signal. That is, it is an AM signal. In one embodiment, the harmonically rich signal **3114** has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave,

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will have sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich signal 3114 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself.

Those skilled in the relevant art(s) will recognize that alternate embodiments exist wherein combinations of modulations (e.g., PM and ASK, FM and AM, etc.) may be employed simultaneously. In these alternate embodiments, the oscillating signal 3104 may be modulated. These alternate embodiments will be apparent to persons skilled in the relevant art(s), and thus will not be described herein.

#### 3.3.7.2 Structural Description.

The switch module 3102 of the present invention is comprised of a first input 3108, a second input 3110, a control input 3120, an output 3122, and a switch 3116. A reference signal 3106 is applied to the first input 3108 of the switch module 3102. Generally, the reference signal 3106 is a function of the information signal 2702, and may either be the summation of the information signal 2702 with a bias signal or it may be the information signal 2702 by itself. In one embodiment of the invention, a resistor 3124 is located between the reference signal 3106 and the switch 3116. The second input 3110 of the switch module 3102 is generally at electrical ground 3112, however, one skilled in the relevant art(s) will recognize that alternative embodiments exist wherein the second input 3110 may not be at electrical ground 3112, but rather connected to a second signal 3118. In an alternate embodiment, the inverted value of the reference signal 3106 is connected to the second input 3110 of the switch module 3102.

An oscillating signal 3104 is connected to the control input 3120 of the switch module 3102. Generally, in the AM mode, the oscillating signal 3104 is not modulated, but a person skilled in the relevant art(s) will recognize that there are embodiments wherein the oscillating signal 3104 may be frequency modulated or phase modulated, but these will not be described herein. The oscillating signal 3104 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. The oscillating signal 3104 causes the switch 3116 to close and open.

The harmonically rich signal 3114 described in section 3.3.7.1 above is found at the output 3122 of the switch module 3102. The harmonically rich signal 3114 is a continuous and periodic waveform whose amplitude is a function of the amplitude of the reference signal. In one embodiment, the harmonically rich signal 3114 has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich signal 3114 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. As previously described, the relative amplitude of the harmonics of a continuous periodic waveform is generally a function of the ratio of the pulse width of the rectangular wave and the period of the fundamental frequency, and can be determined by doing a Fourier analysis of the periodic waveform. When the amplitude of the periodic waveform varies, as in the AM mode of the invention, the change in amplitude of the periodic waveform has a proportional effect on the absolute amplitude of the harmonics. In other words, the AM is embedded on top of each of the harmonics.

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The description of the switch module 3102 is substantially as follows: When the switch 3116 is "open," the amplitude of the harmonically rich signal 3114 is substantially equal to the reference signal 3106. When the oscillating signal 3104 causes the switch 3116 to become "closed," the output 3122 of the switch module 3102 becomes connected electrically to the second input 3110 of the switch module 3102 (e.g., ground 3112 in one embodiment), and the amplitude of the harmonically rich signal 3114 becomes equal to the value of the second input 3110 (e.g., zero volts for the embodiment wherein the second input 3110 is connected to electrical ground 3112). When the oscillating signal 3104 causes the switch 3116 to again become "open," the amplitude of the harmonically rich signal 3114 again becomes substantially equal to the reference signal 3106. Thus, the amplitude of the harmonically rich signal 3114 is at either of two signal levels, i.e., reference signal 3106 or ground 3112, and has a frequency that is substantially equal to the frequency of the oscillating signal 3104 that causes the switch 3116 to open and close. In an alternate embodiment wherein the second input 3110 is connected to the second signal 3118, the harmonically rich signal 3114 varies between the reference signal 3106 and the second signal 3118. One skilled in the relevant art(s) will recognize that any one of a number of switch module designs will fulfill the scope and spirit of the present invention.

In an embodiment of the invention, the switch 3116 is a semiconductor device, such as a diode ring. In another embodiment, the switch is a transistor, such as, but not limited to, a field effect transistor (FET). In an embodiment wherein the FET is gallium arsenide (GaAs), the module can be designed as seen in FIGS. 32A-32C, where the oscillating signal 3104 is connected to the gate 3202 of the GaAsFET 3201, the reference signal 3106 is connected to the source 3204, and electrical ground 3112 is connected to the drain 3206 (in the embodiment where ground 3112 is selected as the value of the second input 3110 of the switch module 3102). Since the drain and the source of GaAsFETs are interchangeable, the reference signal 3106 can be applied to either the source 3204 or to the drain 3206. If there is concern that there might be some source-drain asymmetry in the GaAsFET 3201, the switch 3116 can be designed as shown in FIGS. 33A-33C, wherein two GaAsFETs 3302 and 3304 are connected together, with the source 3310 of the first 3302 connected to the drain 3312 of the second 3304, and the drain 3306 of the first 3302 being connected to the source 3308 of the second 3304. This design arrangement will substantially balance all asymmetries. Other switch designs and implementations will be apparent to persons skilled in the relevant art(s).

The output 3122 of the switch module 3102, i.e., the harmonically rich signal 3114, can be routed to a filter 3504 in the AM mode.

#### 3.3.8 The Summer ("I/Q" Mode).

As discussed above, the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a summer. See, as an example, summer 1832 in FIG. 18. The invention supports numerous embodiments of the summer. Exemplary embodiments of the summer 3402 (FIG. 34) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

##### 3.3.8.1 Operational Description.

An "I" modulated signal 3404 and a "Q" modulated signal 3406 are combined and an "I/Q" modulated signal 3408 is generated. Generally, both "I" and "Q" modulated signals 3404 and 3406 are harmonically rich waveforms, which are

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referred to as the harmonically rich "I" signal **3404** and the harmonically rich "Q" signal **3406**. Similarly, "I/Q" modulated signal **3408** is harmonically rich and is referred to as the harmonically rich "I/Q" signal. In one embodiment, these harmonically rich signals have substantially rectangular waveforms. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed.

In a typical embodiment, the harmonically rich "I" signal **3404** and the harmonically rich "Q" signal **3406** are phase modulated, as is the harmonically rich "I/Q" signal **3408**. A person skilled in the relevant art(s) will recognize that other modulation techniques, such as amplitude modulating the "I/Q" signal, may also be used in the "I/Q" mode without deviating from the scope and spirit of the invention.

As stated before, a continuous and periodic waveform, such as harmonically rich "I/Q" signal **3408**, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich "I/Q" signal **3408** is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. These sinusoidal signals are also modulated substantially the same as the continuous and periodic waveform from which they are derived. That is, in this embodiment, the sinusoidal signals are phase modulated, and include the information from both the "I" modulated signal and the "Q" modulated signal.

### 3.3.8.2 Structural Description.

The design and use of a summer **3402** is well known to those skilled in the relevant art(s). A summer **3402** may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A summer **3402** accepts a harmonically rich "I" signal **3404** and a harmonically rich "Q" signal **3406**, and combines them to create a harmonically rich "I/Q" signal **3408**. In a preferred embodiment of the invention, the harmonically rich "I" signal **3404** and the harmonically rich "Q" signal **3406** are both phase modulated. When the harmonically rich "I" signal **3404** and the harmonically rich "Q" signal **3406** are both phase modulated, the harmonically rich "I/Q" signal **3408** is also phase modulated.

As stated before, a continuous and periodic waveform, such as the harmonically rich "I/Q" signal **3408**, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich "I/Q" signal **3408** is composed of "I/Q" sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. These "I/Q" sinusoidal signals are also phase modulated substantially the same as the continuous and periodic waveform from which they are derived (i.e., the harmonically rich "I/Q" signal **3408**).

The output of the summer **3402** is then routed to a filter **3504**.

### 3.3.9 The Filter (FM, PM, AM, and "I/Q" Modes).

As discussed above, all modulation mode embodiments of the invention use a filter. See, as an example, filter **1218** in FIG. 12, filter **1414** in FIG. 14, filter **1618** in FIG. 16, and filter **1836** in FIG. 18. The invention supports numerous embodiments of the filter. Exemplary embodiments of the filter **3504** (FIG. 35) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

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### 3.3.9.1 Operational Description.

A modulated signal with a harmonically rich waveform **3502** is accepted. It is referred to as the harmonically rich signal **3502**. As stated above, a continuous and periodic waveform, such as the harmonically rich signal **3502**, is comprised of sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform from which they are derived. These are called the Fourier component frequencies. In one embodiment of the invention, the undesired harmonic frequencies are removed, and the desired frequency **3506** is output. In an alternate embodiment, a plurality of harmonic frequencies are output.

The harmonic components of the harmonically rich signal **3502** are modulated in the same manner as the harmonically rich signal **3502** itself. That is, if the harmonically rich signal **3502** is frequency modulated, all of the harmonic components of that signal are also frequency modulated. The same is true for phase modulation, amplitude modulation, and "I/Q" modulation.

### 3.3.9.2 Structural Description.

The design and use of a filter **3504** is well known to those skilled in the relevant art(s). A filter **3504** may be designed and fabricated from discrete components or it may be purchased "off the shelf." The filter **3504** accepts the harmonically rich signal **3502** from the switch module **2802** or **3102** in the FM, PM, and AM modes, and from the summer **3402** in the "I/Q" mode. The harmonically rich signal **3502** is a continuous and periodic waveform. As such, it is comprised of sinusoidal components (harmonics) that are at frequencies that are integer multiples of the fundamental frequency of the underlying harmonically rich signal **3502**. The filter **3504** removes those sinusoidal signals having undesired frequencies. The signal **3506** that remains is at the desired frequency, and is called the desired output signal **3506**.

To achieve this result, according to an embodiment of the invention, a filter **3504** is required to filter out the unwanted harmonics of the harmonically rich signal **3502**.

The term "Q" is used to represent the ratio of the center frequency of the desired output signal **3506** to the half power band width. Looking at FIG. 36 we see a desired frequency **3602** of 900 MHz. The filter **3504** is used to ensure that only the energy at that frequency **3602** is transmitted. Thus, the bandwidth **3604** at half power (the so-called "3 dB down" point) should be as narrow as possible. The ratio of frequency **3602** to bandwidth **3604** is defined as "Q." As shown on FIG. 36, if the "3 dB down" point is at plus or minus 15 MHz, the value of Q will be  $900/(15+15)$  or 30. With the proper selection of elements for any particular frequency, Qs on the order of 20 or 30 are achievable.

For crisp broadcast frequencies, it is desired that Q be as high as possible and practical, based on the given application and environment. The purpose of the filter **3504** is to filter out the unwanted harmonics of the harmonically rich signal. The circuits are tuned to eliminate all other harmonics except for the desired frequency **3506** (e.g., the 900 MHz harmonic **3602**). Turning now to FIGS. 37A and 37B, we see examples of filter circuits. One skilled in the relevant art(s) will recognize that a number of filter designs will accomplish the desired goal of passing the desired frequency while filtering the undesired frequencies.

FIG. 37A illustrates a circuit having a capacitor in parallel with an inductor and shunted to ground. In FIG. 37B, a capacitor is in series with an inductor, and a parallel circuit similar to that in FIG. 37A is connected between the capacitor and inductor and shunted to ground.

The modulated signal at the desired frequency **3506** may then be routed to the transmission module **3804**.

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3.3.10 The Transmission Module (FM, PM, AM, and “I/Q” Modes).

As discussed above, the modulation mode embodiments of the invention preferably use a transmission module. See, as an example, transmission module **1222** in FIG. **12**, transmission module **1418** in FIG. **14**, transmission module **1622** in FIG. **16**, and transmission module **1840** in FIG. **18**. The transmission module is optional, and other embodiments may not include a transmission module. The invention supports numerous embodiments of the transmission module. Exemplary embodiments of the transmission module **3804** (FIG. **38**) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

3.3.10.1 Operational Description.

A modulated signal at the desired frequency **3802** is accepted and is transmitted over the desired medium, such as, but not limited to, over-the-air broadcast or point-to-point cable.

3.3.10.2 Structural Description.

The transmission module **3804** receives the signal at the desired EM frequency **3802**. If it is intended to be broadcast over the air, the signal may be routed through an optional antenna interface and then to the antenna for broadcast. If it is intended for the signal to be transmitted over a cable from one point to another, the signal may be routed to an optional line driver and out through the cable. One skilled in the relevant art(s) will recognize that other transmission media may be used.

3.3.11 Other Implementations.

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Other implementation embodiments are possible and covered by the invention, such as but not limited to software, software/hardware, and firmware implementations of the systems and components of the invention. Alternate implementations and embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

4. Harmonic Enhancement.

4.1 High Level Description.

This section (including its subsections) provides a high-level description of harmonic enhancement according to the present invention. In particular, pulse shaping is described at a high-level. Also, a structural implementation for achieving this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

It is noted that some embodiments of the invention include harmonic enhancement, whereas other embodiments do not.

4.1.1 Operational Description.

To better understand the generation and extraction of harmonics, and the purpose behind shaping the waveforms to enhance the harmonics, the following discussion of Fourier analysis as it applies to the present invention is offered.

A discovery made by Baron Jean B. J. Fourier (1768-1830) showed that continuous and periodic waveforms are comprised of a plurality of sinusoidal components, called harmonics. More importantly, the frequency of these components are integer multiples of the frequency of the original

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waveform (called the fundamental frequency). The amplitude of each of these component waveforms depends on the shape of the original waveform. The derivations and proofs of Baron Fourier's analysis are well known to those skilled in the relevant art(s).

The most basic waveform which is continuous and periodic is a sine wave. It has but one harmonic, which is at the fundamental frequency. This is also called the first harmonic. Since it only has one component, the amplitude of the harmonic component is equal to the amplitude of the original waveform, i.e., the sine wave itself. The sine wave is not considered to be “harmonically rich.”

An impulse train is the other extreme case of a periodic waveform. Mathematically, it is considered to have zero width. The mathematical analysis in this case shows that there are harmonics at all multiples of the frequency of the impulse. That is, if the impulse has a frequency of  $F_p$ , then the harmonics are sinusoidal waves at  $1 \cdot F_p$ ,  $2 \cdot F_p$ ,  $3 \cdot F_p$ ,  $4 \cdot F_p$ , etc. As the analysis also shows in this particular case, the amplitude of all of the harmonics are equal. This is indeed, a “harmonically rich” waveform, but is realistically impractical with current technology.

A more typical waveform is a rectangular wave, which is a series of pulses. Each pulse will have a width (called a pulse width, or “ $\tau$ ”), and the series of pulses in the waveform will have a period (“ $T$ ”) which is the inverse of the frequency, i.e.,  $1/F_p$  where “ $F_p$ ” is the fundamental frequency of the rectangular wave). One form of rectangular wave is the square wave, where the signal is at a first state (e.g., high) for the same amount of time that it is at the second state (e.g., low). That is, the ratio of the pulse width to period ( $\tau/T$ ) is 0.5. Other forms of rectangular waves, other than square waves, are typically referred to simply as “pulses,” and have  $\tau/T < 0.5$  (i.e., the signal will be “high” for a shorter time than it is “low”). The mathematical analysis shows that there are harmonics at all of the multiples of the fundamental frequency of the signal. Thus, if the frequency of the rectangular waveform is  $F_p$ , then the frequency of the first harmonic is  $1 \cdot F_p$ , the frequency of the second harmonic is  $2 \cdot F_p$ , the frequency of the third harmonic is  $3 \cdot F_p$ , and so on. There are some harmonics for which the amplitude is zero. In the case of a square wave, for example, the “null points” are the even harmonics. For other values of  $\tau/T$ , the “null points” can be determined from the mathematical equations. The general equation for the amplitude of the harmonics in a rectangular wave having an amplitude of  $A_{pulse}$  is as follows:

$$\text{Amplitude}(n^{\text{th}} \text{ harmonic}) = A_n = \{ [A_{pulse}] [(2/\pi)/n] \sin [n \cdot \pi (\tau/T)] \} \quad \text{Eq. 1}$$

Table **6000** of FIG. **60** shows the amplitudes of the first fifty harmonics for rectangular waves having six different  $\tau/T$  ratios. The  $\tau/T$  ratios are 0.5 (a square wave), 0.25, 0.10, 0.05, 0.01, and 0.005. (One skilled in the relevant art(s) will recognize that  $A_{pulse}$  is set to unity for mathematical comparison.) From this limited example, it can be seen that the ratio of pulse width to period is a significant factor in determining the relative amplitudes of the harmonics. Notice too, that for the case where  $\tau/T = 0.5$  (i.e., a square wave), the relationship stated above (i.e., only odd harmonics are present) holds. Note that as  $\tau/T$  becomes small (i.e., the pulse approaches an impulse), the amplitudes of the harmonics becomes substantially “flat.” That is, there is very little decrease in the relative amplitudes of the harmonics. One skilled in the relevant art(s) will understand how to select the desired pulse width for any given application based on the teachings contained herein. It can also be shown mathematically and experimentally that if

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a signal with a continuous and periodic waveform is modulated, that modulation is also present on every harmonic of the original waveform.

From the foregoing, it can be seen how pulse width is an important factor in assuring that the harmonic waveform at the desired output frequency has sufficient amplitude to be useful without requiring elaborate filtering or unnecessary amplification.

Another factor in assuring that the desired harmonic has sufficient amplitude is how the switch **2816** and **3116** (FIGS. **28A** and **31A**) in the switch module **2802** and **3102** responds to the control signal that causes the switch to close and to open (i.e., the modulated oscillating signal **2804** of FIG. **28** and the oscillating signal **3104** of FIG. **31**). In general, switches have two thresholds. In the case of a switch that is normally open, the first threshold is the voltage required to cause the switch to close. The second threshold is the voltage level at which the switch will again open. The convention used herein for ease of illustration and discussion (and not meant to be limiting) is for the case where the switch is closed when the control signal is high, and open when the control signal is low. It would be apparent to one skilled in the relevant art(s) that the inverse could also be used. Typically, these voltages are not identical, but they may be. Another factor is how rapidly the switch responds to the control input once the threshold voltage has been applied. The objective is for the switch to close and open such that the bias/reference signal is “crisply” gated. That is, preferably, the impedance through the switch must change from a high impedance (an open switch) to a low impedance (a closed switch) and back again in a very short time so that the output signal is substantially rectangular.

It is an objective of this invention in the transmitter embodiment that the intelligence in the information signal is to be transmitted. That is, the information is modulated onto the transmitted signal. In the FM and PM modes, to achieve this objective, the information signal is used to modulate the oscillating signal **2804**. The oscillating signal **2804** then causes the switch **2816** to close and open. The information that is modulated onto the oscillating signal **2804** must be faithfully reproduced onto the signal that is output from the switch circuit (i.e., the harmonically rich signal **2814**). For this to occur efficiently, in embodiments of the invention, the switch **2816** preferably closes and opens crisply so that the harmonically rich signal **2814** changes rapidly from the bias/reference signal **2806** (or **3106**) to ground **2812** (or the second signal level **2818** in the alternate embodiment). This rapid rise and fall time is desired so that the harmonically rich signal **2814** will be “harmonically rich.” (In the case of AM, the oscillating signal **3104** is not modulated, but the requirement for “crispness” still applies.)

For the switch **2816** to close and open crisply, the oscillating signal **2804** must also be crisp. If the oscillating signal **2804** is sinusoidal, the switch **2816** will open and close when the threshold voltages are reached, but the pulse width of the harmonically rich signal **2814** may not be as small as is needed to ensure the amplitude of the desired harmonic of the harmonically rich signal **2814** is sufficiently high to allow transmission without elaborate filtering or unnecessary amplification. Also, in the embodiment wherein the switch **2816** is a GaAsFET **2901**, if the oscillating signal **2804** that is connected to the gate **2902** of the GaAsFET **2901** (i.e., the signal that causes the switch **2816** to close and open) is a sinusoidal wave, the GaAsFET **2901** will not crisply close and open, but will act more like an amplifier than a switch. (That is, it will conduct during the time that the oscillating signal is rising and falling below the threshold voltages, but will not be a “short.”) In order to make use of the benefits of

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a GaAsFET’s capability to close and open at high frequencies, the oscillating signal **2804** connected to the gate **2902** preferably has a rapid rise and fall time. That is, it is preferably a rectangular waveform, and preferably has a pulse width to period ratio the same as the pulse width to period ratio of the harmonically rich signal **2814**.

As stated above, if a signal with a continuous and periodic waveform is modulated, that modulation occurs on every harmonic of the original waveform. Thus, in the FM and PM modes, when the information is modulated onto the oscillating signal **2804** and the oscillating signal **2804** is used to cause the switch **2816** to close and open, the resulting harmonically rich signal **2814** that is output from the switch module **2802** will also be modulated. If the oscillating signal **2804** is crisp, the switch **2816** will close and open crisply, the harmonically rich signal **2814** will be harmonically rich, and each of the harmonics of the harmonically rich signal **2814** will have the information modulated on it.

Because it is desired that the oscillating signal **2804** be crisp, harmonic enhancement may be needed in some embodiments. Harmonic enhancement may also be called “pulse shaping” since the purpose is to shape the oscillating signal **2804** into a string of pulses of a desired pulse width. If the oscillating signal is sinusoidal, harmonic enhancement will shape the sinusoidal signal into a rectangular (or substantially rectangular) waveform with the desired pulse width to period ratio. If the oscillating signal **2804** is already a square wave or a pulse, harmonic enhancement will shape it to achieve the desired ratio of pulse width to period. This will ensure an efficient transfer of the modulated information through the switch.

Three exemplary embodiments of harmonic enhancement are described below for illustrative purposes. However, the invention is not limited to these embodiments. Other embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

#### 4.1.2 Structural Description.

The shape of the oscillating signal **2804** causes the switch **2816** to close and open. The shape of the oscillating signal **2804** and the selection of the switch **2816** will determine how quickly the switch **2816** closes and opens, and how long it stays closed compared to how long it stays open. This then will determine the “crispness” of the harmonically rich signal **2814**. (That is, whether the harmonically rich signal **2814** is substantially rectangular, trapezoidal, triangular, etc.) As shown above, in order to ensure that the desired harmonic has the desired amplitude, the shape of the oscillating signal **2804** should be substantially optimized.

The harmonic enhancement module (HEM) **4602** (FIG. **46**) is also referred to as a “pulse shaper.” It “shapes” the oscillating signals **2804** and **3104** that drive the switch modules **2802** and **3102** described in sections 3.3.6-3.3.6.2 and 3.3.7-3.3.7.2. Harmonic enhancement module **4602** preferably transforms a continuous and periodic waveform **4604** into a string of pulses **4606**. The string of pulses **4606** will have a period, “T,” determined by both the frequency of the continuous and periodic waveform **4604** and the design of the pulse shaping circuit within the harmonic enhancement module **4602**. Also, each pulse will have a pulse width, “ $\tau$ ,” determined by the design of the pulse shaping circuit. The period of the pulse stream, “T,” determines the frequency of the switch closing (the frequency being the inverse of the period), and the pulse width of the pulses, “ $\tau$ ,” determines how long the switch stays closed.

In the embodiment described above in sections 3.3.6-3.3.6.2 (and 3.3.7-3.3.7.2), when the switch **2816** (or **3116**) is open, the harmonically rich signal **2814** (or **3114**) will have an

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amplitude substantially equal to the bias signal **2806** (or reference signal **3106**). When the switch **2816** (or **3116**) is closed, the harmonically rich signal **2814** (or **3114**) will have an amplitude substantially equal to the potential of signal **2812** or **2818** (or **3112** or **3118**) of the second input **2810** (or **3110**) of the switch module **2802** (or **3102**). Thus, for the case where the oscillating signal **2804** (or **3104**) driving the switch module **2802** (or **3102**) is substantially rectangular, the harmonically rich signal **2814** (or **3114**) will have substantially the same frequency and pulse width as the shaped oscillating signal **2804** (or **3104**) that drives the switch module **2802** (or **3102**). This is true for those cases wherein the oscillating signal **2804** (or **3104**) is a rectangular wave. One skilled in the relevant art(s) will understand that the term "rectangular wave" can refer to all waveforms that are substantially rectangular, including square waves and pulses.

The purpose of shaping the signal is to control the amount of time that the switch **2816** (or **3116**) is closed. As stated above, the harmonically rich signal **2814** (or **3114**) has a substantially rectangular waveform. Controlling the ratio of the pulse width of the harmonically rich signal **2814** (or **3114**) to its period will result in the shape of the harmonically rich signal **2814** (or **3114**) being substantially optimized so that the relative amplitudes of the harmonics are such that the desired harmonic can be extracted without unnecessary and elaborate amplification and filtering.

#### 4.2 Exemplary Embodiments.

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

##### 4.2.1 First Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create One Pulse per Cycle.

###### 4.2.1.1 Operational Description.

According to this embodiment, a continuous periodic waveform **4604** is received and a string of pulses **4606** is output. The continuous periodic waveform **4604** may be a square wave or any other continuous periodic waveform that varies from a value recognized as a "digital low" to a value recognized as a "digital high." One pulse is generated per cycle of the continuous and periodic waveform **4604**. The description given herein will be for the continuous periodic waveform **4604** that is a square wave, but one skilled in the relevant art(s) will appreciate that other waveforms may also be "shaped" into waveform **4606** by this embodiment.

###### 4.2.1.2 Structural Description.

In this first embodiment of a harmonic enhancement module **4602**, herein after referred to as a pulse shaping circuit **4602**, a continuous periodic waveform **4604** that is a square wave is received by the pulse shaping circuit **4602**. The pulse shaping circuit **4602** is preferably comprised of digital logic devices that result in a string of pulses **4606** being output that has one pulse for every pulse in the continuous periodic waveform **4604**, and preferably has a  $\tau/T$  ratio less than 0.5.

##### 4.2.2 Second Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create Two Pulses per Cycle.

###### 4.2.2.1 Operational Description.

In this embodiment, a continuous periodic waveform **4604** is received and a string of pulses **4606** is output. In this

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embodiment, there are two pulses output for every period of the continuous periodic waveform **4604**. The continuous periodic waveform **4604** may be a square wave or any other continuous periodic waveform that varies from a value recognized as a "digital low" to a value recognized as a "digital high." The description given herein will be for a continuous periodic waveform **4604** that is a square wave, but one skilled in the relevant art(s) will appreciate that other waveforms may also be "shaped" into waveform **4606** by this embodiment.

###### 4.2.2.2 Structural Description.

In this second embodiment of a pulse shaping circuit **4602**, a continuous periodic waveform **4604** that is a square wave is received by the pulse shaping circuit **4602**. The pulse shaping circuit **4602** is preferably comprised of digital logic devices that result in a string of pulses **4606** being output that has two pulses for every pulse in the continuous periodic waveform **4604**, and preferably has a  $\tau/T$  ratio less than 0.5.

##### 4.2.3 Third Embodiment: When Any Waveform Feeds the Module.

###### 4.2.3.1 Operational Description.

In this embodiment, a continuous periodic waveform **4604** of any shape is received and a string of pulses **4606** is output.

###### 4.2.3.2 Structural Description.

In this third embodiment of a pulse shaping circuit **4602**, a continuous periodic waveform **4604** of any shape is received by the pulse shaping circuit **4602**. The pulse shaping circuit **4602** is preferably comprised of a series of stages, each stage shaping the waveform until it is substantially a string of pulses **4606** with preferably a  $\tau/T$  ratio less than 0.5.

###### 4.2.4 Other Embodiments.

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

##### 4.3 Implementation Examples.

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

###### 4.3.1 First Digital Logic Circuit.

An exemplary implementation of the first embodiment described in sections 4.2.1-4.2.1.2 is illustrated in FIG. 39. In particular, the circuit shown in FIG. 39A is a typical circuit design for a pulse shaping circuit **4602** using digital logic devices. Also shown in FIGS. 39B-39D are representative waveforms at three nodes within the circuit. In this embodiment, pulse shaper **3900** uses an inverter **3910** and an AND gate **3912** to produce a string of pulses. An inverter, such as inverter **3910**, changes the sign of the input, and an AND gate, such as AND gate **3912**, outputs a digital "high" when all of the input signals are digital "highs." The input to pulse shaper **3900** is waveform **3902**, and, for illustrative purposes, is shown here as a square wave. The output of inverter **3910** is waveform **3904**, which is also a square wave. However, because of the circuitry of the inverter **3910**, there is a delay between the application of the input and the corresponding

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sign change of the output. If waveform 3902 starts “low,” waveform 3904 will be “high” because it has been inverted by inverter 3910. When waveform 3902 switches to “high,” AND gate 3912 will momentarily see two “high” signals, thus causing its output waveform 3906 to be “high.” When inverter 3910 has inverted its input (waveform 3902) and caused waveform 3904 to become “low,” AND gate 3912 will then see only one “high” signal, and the output waveform 3906 will become “low.” Thus, the output waveform 3906 will be “high” for only the period of time that both waveforms 3902 and 3904 are high, which is the time delay of the inverter 3910. Accordingly, as is apparent from FIGS. 39B-39D, pulse shaper 3900 receives a square wave and generates a string of pulses, with one pulse generated per cycle of the square wave.

#### 4.3.2 Second Digital Logic Circuit.

An exemplary implementation of the second embodiment described in sections 4.2.2-4.2.2.2 is illustrated in FIG. 40. In particular, the circuit of FIG. 40A is a typical circuit design for a pulse shaping circuit 4602 using digital logic devices. Also shown in FIGS. 40B-40D are representative waveforms at three nodes within the circuit. In this embodiment, pulse shaping circuit 4000 uses an inverter 4010 and an exclusive NOR (XNOR) gate 4012. An XNOR, such as XNOR 4012, outputs a digital “high” when both inputs are digital “highs” and when both signals are digital “lows.” Waveform 4002, which is shown here as a square wave identical to that shown above as waveform 3902, begins in the “low” state. Therefore, the output of inverter 4010 will begin at the “high” state. Thus, XNOR gate 4012 will see one “high” input and one “low” input, and its output waveform 4006 will be “low.” When waveform 4002 changes to “high,” XNOR gate 4012 will have two “high” inputs until the waveform 4004 switches to “low.” Because it sees two “high” inputs, its output waveform 4006 will be “high.” When waveform 4004 becomes “low,” XNOR gate 4012 will again see one “high” input (waveform 4002) and one “low” input (waveform 4004). When waveform 4002 switches back to “low,” XNOR gate 4012 will see two “low” inputs, and its output will become “high.” Following the time delay of inverter 4010, waveform 4004 will change to “high,” and XNOR gate 4012 will again see one “high” input (waveform 4004) and one “low” input (waveform 4002). Thus, waveform 4006 will again switch to “low.” Accordingly, as is apparent from FIGS. 40B-40D, pulse shaper 4000 receives a square wave and generates a string of pulses, with two pulses generated per cycle of the square wave.

#### 4.3.3 Analog Circuit.

An exemplary implementation of the third embodiment described in sections 4.2.3-4.2.3.2 is illustrated in FIG. 41. In particular, the circuit shown in FIG. 41 is a typical pulse shaping circuit 4602 where an input signal 4102 is shown as a sine wave. Input signal 4102 feeds the first circuit element 4104, which in turn feeds the second, and so on. Typically, three circuit elements 4104 produce incrementally shaped waveforms 4120, 4122, and 4124 before feeding a capacitor 4106. The output of capacitor 4106 is shunted to ground 4110 through a resistor 4108 and also feeds a fourth circuit element 4104. An output signal 4126 is a pulsed output, with a frequency that is a function of the frequency of input signal 4102.

An exemplary circuit for circuit elements 4104 is shown in FIG. 43. Circuit 4104 is comprised of an input 4310, an output 4312, four FETs 4302, two diodes 4304, and a resistor 4306. One skilled in the relevant art(s) would recognize that other pulse shaping circuit designs could also be used without deviating from the scope and spirit of the invention.

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#### 4.3.4 Other Implementations.

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

### 5. Amplifier Module

#### 5.1 High Level Description

This section (including its subsections) provides a high-level description of the amplifier module according to the present invention. In particular, amplification is described at a high-level. Also, a structural implementation for achieving signal amplification is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

#### 5.1.1 Operational Description.

Even though the present invention is intended to be used without requiring amplification, there may be circumstance when, in the embodiment of the present invention wherein it is being used as a transmitter, it may prove desirable to amplify the modulated signal before it is transmitted. In another embodiment of the invention wherein it is being used as a stable signal source for a frequency or phase comparator, it may also be desirable to amplify the resultant signal at the desired frequency.

The requirement may come about for a number of reasons.

A first may be that the bias/reference signal is too low to support the desired use. A second may be because the desired output frequency is very high relative to the frequency of the oscillating signal that controls the switch. A third reason may be that the shape of the harmonically rich signal is such that the amplitude of the desired harmonic is low.

In the first case, recall that the amplitude of the bias/reference signal determines the amplitude of the harmonically rich signal which is present at the output of the switch circuit. (See sections 3.3.6-3.3.6.2 and 3.3.7-3.3.7.2.) Further recall that the amplitude of the harmonically rich signal directly impacts the amplitude of each of the harmonics. (See the equation in section 4.1, above.)

In the second instance, if the frequency of the oscillating signal is relatively low compared to the desired output frequency of the up-converter, a high harmonic will be needed. As an example, if the oscillating signal is 60 MHz, and the desired output frequency is at 900 MHz, the 15<sup>th</sup> harmonic will be needed. In the case where  $\tau/T$  is 0.1, it can be seen from Table 6000 of FIG. 60 that the amplitude of the 15<sup>th</sup> harmonic ( $A_{15}$ ) is 0.0424, which is 21.5% of the amplitude of the first harmonic ( $A_1 > 0.197$ ). There may be instances wherein this is insufficient for the desired use, and consequently it must be amplified.

The third circumstance wherein the amplitude of the output may need to be amplified is when the shape of the harmonically rich signal is not “crisp” enough to provide harmonics with enough amplitude for the desired purpose. If, for example, the harmonically rich signal is substantially triangular, and given the example above where the oscillating signal is 60 MHz and the desired output signal is 900 MHz, the 15<sup>th</sup> harmonic of the triangular wave is 0.00180. This is significantly lower than the amplitude of the 15<sup>th</sup> harmonic of

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the “0.1” rectangular wave (shown above to be 0.0424) and can be mathematically shown to be 0.4% of the amplitude of the 1<sup>st</sup> harmonic of the triangular wave (which is 0.405). Thus, in this example, the 1<sup>st</sup> harmonic of the triangular wave has an amplitude that is larger than the amplitude of the 1<sup>st</sup> harmonic of the “0.1” rectangular wave, but at the 15<sup>th</sup> harmonic, the triangular wave is significantly lower than the “0.1” rectangular wave.

Another reason that the desired harmonic may need to be amplified is that circuit elements such as the filter may cause attenuation in the output signal for which a designer may wish to compensate.

The desired output signal can be amplified in a number of ways. One is to amplify the bias/reference signal to ensure that the amplitude of the harmonically rich wave form is high. A second is to amplify the harmonically rich waveform itself. A third is to amplify the desired harmonic only. The examples given herein are for illustrative purposes only and are not meant to be limiting on the present invention. Other techniques to achieve amplification of the desired output signal would be apparent to those skilled in the relevant art(s).

#### 5.1.2 Structural Description.

In one embodiment, a linear amplifier is used to amplify the bias/reference

In another embodiment, a linear amplifier is used to amplify the harmonically rich signal. And in yet another embodiment, a linear amplifier is used to amplify the desired output signal. Other embodiments, including the use of non-linear amplifiers, will be apparent to persons skilled in the relevant art(s).

#### 5.2 Exemplary Embodiment

An embodiment related to the method(s) and structure(s) described above is presented in this section (and its subsections). This embodiment is described herein for purposes of illustration, and not limitation. The invention is not limited to this embodiment. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiment described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

##### 5.2.1 Linear Amplifier

The exemplary linear amplifier described herein will be directed towards an amplifier composed of solid state electronic devices to be inserted in the circuit at one or more points. Other amplifiers suitable for use with the invention will be apparent to persons skilled in the relevant art(s). As shown in FIG. 47, an amplifier module 4702 receives a signal requiring amplification 4704 and outputs an amplified signal 4706. It would be apparent to one skilled in the relevant art(s) that a plurality of embodiments may be employed without deviating from the scope and intent of the invention described herein.

##### 5.2.1.1 Operational Description.

The desired output signal can be amplified in a number of ways. Such amplification as described in the section may be in addition to the techniques described above to enhance the shape of the harmonically rich signal by pulse shaping of the oscillating signal that causes the switch to close and open.

##### 5.2.1.2 Structural Description.

In one embodiment, a linear amplifier is placed between the bias/reference signal and the switch module. This will increase the amplitude of the bias/reference signal, and as a result, will raise the amplitude of the harmonically rich signal that is the output of the switch module. This will have the effect of not only raising the amplitude of the harmonically rich signal, it will also raise the amplitude of all of the har-

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monics. Some potential limitation of this embodiment are: the amplified bias/reference signal may exceed the voltage design limit for the switch in the switch circuit; the harmonically rich signal coming out of the switch circuit may have an amplitude that exceeds the voltage design limits of the filter; and/or unwanted distortion may occur from having to amplify a wide bandwidth signal.

A second embodiment employs a linear amplifier between the switch module and the filter. This will raise the amplitude of the harmonically rich signal. It will also raise the amplitude of all of the harmonics of that signal. In an alternate implementation of this embodiment, the amplifier is tuned so that it only amplifies the desired frequencies. Thus, it acts both as an amplifier and as a filter. A potential limitation of this embodiment is that when the harmonically rich signal is amplified to raise a particular harmonic to the desired level the amplitude of the whole waveform is amplified as well. For example, in the case where the amplitude of the pulse,  $A_{pulse}$ , is equal to 1.0, to raise the 15<sup>th</sup> harmonic from 0.0424 volts to 0.5 volts, the amplitude of each pulse in the harmonically rich signal,  $A_{pulse}$ , will increase from 1.0 to 11.8 volts. This may well exceed the voltage design limit of the filter.

A third embodiment of an amplifier module will place a linear amplifier between the filter and the transmission module. This will only raise the amplitude of the desired harmonic, rather than the entire harmonically rich signal.

Other embodiments, such as the use of non-linear amplifiers, will be apparent to one skilled in the relevant art(s), and will not be described herein.

#### 5.2.2 Other Embodiments

The embodiments described above are for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

#### 5.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

##### 5.3.1 Linear Amplifier.

Although described below as if it were placed after the filter, the amplifier may also be placed before the filter without deviating from the intent of the invention

##### 5.3.1.1 Operational Description.

According to embodiments of the invention, a linear amplifier receives a first signal at a first amplitude, and outputs a second signal at a second amplitude, wherein the second signal is proportional to the first signal. It is an objective of an amplifier that the information embedded onto the first signal waveform will also be embedded onto the second signal. Typically, it is desired that there be as little distortion in the information as possible.

In a preferred embodiment, the second signal is higher in amplitude than the first signal, however, there may be imple-

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mentations wherein it is desired that the second signal be lower than the first signal (i.e., the first signal will be attenuated).

#### 5.3.1.2 Structural Description.

The design and use of a linear amplifier is well known to those skilled in the relevant art(s). A linear amplifier may be designed and fabricated from discrete components, or it may be purchased "off the shelf."

Exemplary amplifiers are seen in FIG. 48. In the exemplary circuit diagram of FIG. 48A, six transistors are used in a wideband amplifier. In the more basic exemplary circuit of FIG. 48B, the amplifier is composed of one transistor, four resistors, and a capacitor. Those skilled in the relevant art(s) will recognize that numerous alternative designs may be used.

#### 5.3.2 Other Implementations.

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

#### Receiver/Transmitter System.

The present invention is for a method and system for up-conversion of electromagnetic signals. In one embodiment, the invention is a source of a stable high frequency reference signal. In a second embodiment, the invention is a transmitter.

This section describes a third embodiment. In the third embodiment, the transmitter of the present invention to be used in a receiver/transmitter communications system. This third embodiment may also be referred to as the communications system embodiment, and the combined receiver/transmitter circuit is referred to as a "transceiver." There are several alternative enhancements to the communications systems embodiment.

The following sections describe systems and methods related to exemplary embodiments for a receiver/transmitter system. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

#### High Level Description.

This section provides a high-level description of a receiver/transmitter system according to the present invention. The implementations are described herein for illustrative purposes, and are not limiting. In particular, any number of functional and structural implementations may be used, several of which are described in this section. The details of such functional and structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

According to a first embodiment of the transmitter of the present invention is used with a traditional superheterodyne receiver. In this embodiment, the transmitter and the receiver can operate either in a full-duplex mode or in a half-duplex mode. In a full duplex mode, the transceiver can transmit and receive simultaneously. In the half-duplex mode, the transceiver can either transmit or receive, but cannot do both simultaneously. The full-duplex and the half-duplex modes will be discussed together for this embodiment.

A second embodiment of the transceiver is for the transmitter of the present invention to be used with a universal

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frequency down conversion circuit being used as a receiver. In this embodiment the transceiver is used in a half-duplex mode.

A third embodiment of the transceiver is for the transmitter of the present invention to be used with a universal frequency down conversion circuit, where the transceiver is used in a full-duplex mode.

These embodiments of the transceiver are described below. Exemplary Embodiments and Implementation Examples

Various embodiments related to the method(s) and structure(s) described above and exemplary operational and/or structural implementations related to those embodiments are presented in this section (and its subsections). These embodiments, components, and methods are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments or to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention, and the invention is intended and adapted to include such alternatives.

First Embodiment: The Transmitter of the Present Invention Being Used in a Circuit with a Superheterodyne Receiver.

A typical superheterodyne receiver is shown in FIG. 49. An antenna 4904 receives a signal 4902. Typically, signal 4902 is a radio frequency (RF) signal which is routed to a filter 4910 and an amplifier 4908. The filter 4910 removes all but a frequency range that includes the desired frequency, and the amplifier 4908 ensures that the signal strength will be sufficient for further processing. The output of amplifier 4908 is a signal 4911.

A local oscillator 4914 generates an oscillating signal 4916 which is combined with signal 4911 by mixer 4912. The output of mixer 4912 is a signal 4934 which is amplified by an amplifier 4918 and filtered by a filter 4920. The purpose of amplifier 4918 is to ensure that the strength of signal 4934 is sufficient for further processing, and the purpose of filter 4920 is to remove the undesired frequencies.

A second local oscillator 4924 generates a second oscillating signal 4926 which is combined with the amplified/filtered signal 4934 by a mixer 4922. The output of mixer 4922 is signal 4936. Again, an amplifier 4928 and a filter 4930 ensure that the signal 4936 is at the desired amplitude and frequency. The resulting signal is then routed to decoder 4932 where the intelligence is extracted to obtain baseband signal 4938.

Signal 4934 is referred to as the first intermediate frequency (IF) signal, and signal 4936 is referred to as the second IF signal. Thus, the combination of local oscillator 4914 and mixer 4912 can be referred to as the first IF stage, and the combination of local oscillator 4924 and mixer 4922 can be referred to as the second IF stage.

Exemplary frequencies for the circuit of FIG. 49 are as follows. Signal 4902 may be 900 MHz. The oscillator signal 4916 may be at 830 MHz, which will result in the frequency of the first IF signal, signal 4934, being at 70 MHz. If the second oscillating signal 4926 is at 59 MHz, the second IF signal, signal 4936, would be at 11 MHz. This frequency is typical of second IF frequencies.

Other superheterodyne receiver configurations are well known and these can be used in the transceiver embodiments of the invention. Also, the exemplary frequencies mentioned above are provide for illustrative purposes only, and are not limiting.

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FIG. 50 shows a transmitter of the present invention in a transceiver circuit with a typical superheterodyne receiver. Accordingly, FIG. 50 illustrates an exemplary transceiver circuit of the invention. The transceiver includes a receiver module 5001, which is implemented using any superheterodyne receiver configuration, and which is described above. The transceiver also includes a transmitter module 5003, which is described below.

In the FM and PM modes, an information signal 5004 modulates an intermediate signal to produce the oscillating signal 5002. Oscillating signal 5002 is shaped by signal shaper 5010 to produce a string of pulses 5008 (see the discussion above regarding the benefits of harmonic enhancement). The string of pulses 5008 drives the switch module 5012. In the FM/PM modes, a bias/reference signal 5006 is also received by switch module 5012. The output of switch module 5012 is a harmonically rich signal 5022. Harmonically rich signal 5022 is comprised of a plurality of sinusoidal components, and is routed to a "high Q" filter that will remove all but the desired output frequency(ies). The desired output frequency 5024 is amplified by an amplifier 5016 and routed to a transmission module 5018 which outputs a transmission signal 5026 which is routed to a duplexer 5020. The purpose of duplexer 5020 is to permit a single antenna to be used simultaneously for both receiving and transmitting signals. The combination of received signal 4902 and transmission signal 5026 is a duplexed signal 5028.

In the AM mode, the same circuit of FIG. 50 applies, except: (1) an information signal 5030 replaces information signal 5004; (2) bias/reference signal 5006 is a function of the information signal 5030; and (3) oscillating signal 5002 is not modulated.

This description is for the full-duplex mode of the transceiver wherein the transmitting portion of the communications system is a separate circuit than the receiver portion. A possible embodiment of a half-duplex mode is described below.

Alternate embodiments of the transceiver are possible. For example, FIGS. 51A through 51D illustrate an embodiment of the transceiver wherein it may be desired, for cost or other considerations, for an oscillator to be shared by both the transmitter portion and the receiver portion of the circuit. To do this, a trade off must be made in selecting the frequency of the oscillator. In FIG. 51A, a local oscillator 5104 generates an oscillating signal 5106 which is mixed with signal 4911 to generate a first IF signal 5108. A local oscillator 5110 generates a second oscillating signal 5112 which is mixed with the first IF signal 5108 to generate a second IF signal 5114. For the example herein, the frequencies of the oscillating signals 5106 and 5112 will be lower than the frequencies of signal 4911 and first IF signal 5108, respectively. (One skilled in the relevant art(s) will recognize that, because the mixers 4912 and 4922 create both the sum and the difference of the signals they receive, the oscillator frequencies could be higher than the signal frequencies.)

As described in the example above, a typical second IF frequency is 11 MHz. The selection of this IF frequency is less flexible than is the selection of the first IF frequency, since the second IF frequency is routed to a decoder where the signal is demodulated and decoded. Typically, demodulators and decoders are designed to receive signals at a predetermined, fixed frequency, e.g., 11 MHz. If this is the case, the combination of the first IF signal 5108 and the second oscillating signal 5112 must generate a second IF signal with a second IF frequency of 11 MHz. Recall that the received signal 4902 was 900 MHz in the example above. To achieve the second IF signal frequency of 11 MHz, the frequencies of

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the oscillating signals 4916 and 4926 were set at 830 MHz and 59 MHz. Before setting the frequencies of the oscillating signals 5106 and 5112, the desired frequency of the transmitted signal must be determined. If it, too, is 900 MHz, then the frequency of the oscillating signal that causes the switch in the present invention to open and close must be a "sub-harmonic" of 900 MHz. That is, it must be the quotient of 900 MHz divided by an integer. (In other words, 900 MHz must be a harmonic of the oscillating signal that drives the switch.) The table below is a list of some of the sub-harmonics of 900 MHz:

sub-harmonic	frequency
1 <sup>st</sup>	900 MHz
2 <sup>nd</sup>	450
3 <sup>rd</sup>	300
4 <sup>th</sup>	225
5 <sup>th</sup>	180
10 <sup>th</sup>	90
15 <sup>th</sup>	60

Recall that the frequency of the second oscillating signal 4926 in FIGS. 49 and 50 was 59 MHz. Notice that the frequency of the 15<sup>th</sup> sub-harmonic is 60 MHz. If the frequency of oscillating signal 5112 of FIG. 51 were set at 60 MHz, it could also be used as the oscillating signal to operate the switches in switch module 5126 of FIG. 51B and switch module 5136 of FIG. 51C. If this were done, the frequency of the first IF signal would be 71 MHz (rather than 70 MHz in the previous example of a stand-alone receiver), as indicated below:

$$\begin{aligned}
 \text{First IF frequency} &= \text{Second IF frequency} + \\
 &\quad \text{Second oscillating frequency} \\
 &= 11 \text{ MHz} + 60 \text{ MHz} \\
 &= 71 \text{ MHz}
 \end{aligned}$$

The frequency of the first oscillating signal 5106 can be determined from the values of the first IF frequency and the frequency of the received signal 4902. In this example, the frequency of the received signal is 900 MHz and the frequency of the first IF signal is 71 MHz. Therefore, the frequency of the first oscillating signal 5106 must be 829 MHz, as indicated below:

$$\begin{aligned}
 \text{First oscillating frequency} &= \text{Freq of received signal} - \\
 &\quad \text{First IF freq} \\
 &= 900 \text{ MHz} - 71 \text{ MHz} \\
 &= 829 \text{ MHz}
 \end{aligned}$$

Thus the frequencies of the oscillating signals 5106 and 5112 are 829 MHz and 60 MHz, respectively.

In FIG. 51B, the PM embodiment is shown. The second oscillating signal 5112 is routed to a phase modulator 5122 where it is modulated by the information signal 5120 to generate a PM signal 5132. PM signal 5132 is routed to a harmonic enhancement module 5124 to create a string of pulses 5133. The string of pulses 5133 is also a phase modulated signal and is used to cause the switch in switch module

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5126 to open and close. Also entering switch module 5126 is a bias signal 5128. The output of switch module 5126 is a harmonically rich signal 5134.

In FIG. 51C, the AM embodiment is shown. The second oscillating signal 5112 directly enters the harmonic enhancement module 5124 to create a string of pulses 5138. String of pulses 5138 (not modulated in this embodiment) then enters a switch module 5136 where it causes a switch to open and close. Also entering switch module 5136 is a reference signal 5140. Reference signal is created by summing module 5130 by combining information signal 5120 with bias signal 5128. It is well known to those skilled in the relevant art(s) that the information signal 5120 may be used as the reference signal without being combined with the bias signal 5128. The output of switch module 5136 is a harmonically rich signal 5134.

The scope of the invention includes an FM embodiment wherein the oscillator 5110 of the receiver circuit is used as a source for an oscillating signal for the transmitter circuit. In the embodiments discussed above, the FM embodiment requires a voltage controlled oscillator (VCO) rather than a simple local oscillator. There are circuit designs that would be apparent to those skilled in the relevant art(s) based on the discussion contained herein, wherein a VCO is used in place of a local oscillator in the receiver circuit.

In FIG. 51D, the harmonically rich signal 5134 is filtered by a filter 5142, which removes all but the desired output frequency 5148. The desired output frequency 5148 is amplified by amplifier module 5146 and routed to transmission module 5150. The output of transmission module 5150 is a transmission signal 5144. Transmission signal 5144 is then routed to the antenna 4904 for transmission.

Those skilled in the relevant art(s) will understand that there are numerous combinations of oscillator frequencies, stages, and circuits that will meet the scope and intent of this invention. Thus, the description included herein is for illustrative purposes only and not meant to be limiting.

Second Embodiment: The Transmitter of the Present Invention Being Used with a Universal Frequency Down-Converter in a Half-Duplex Mode.

An exemplary receiver using universal frequency down conversion techniques is shown in FIG. 52 and described in section 6.3, below. An antenna 5202 receives an electromagnetic (EM) signal 5220. EM signal 5220 is routed through a capacitor 5204 to a first terminal of a switch 5210. The other terminal of switch 5210 is connected to ground 5212 in this exemplary embodiment. A local oscillator 5206 generates an oscillating signal 5228 which is routed through a pulse shaper 5208. The result is a string of pulses 5230. The selection of the oscillator 5206 and the design of the pulse shaper 5208 control the frequency and pulse width of the string of pulses 5230. The string of pulses 5230 control the opening and closing of switch 5210. As a result of the opening and closing of switch 5210, a down converted signal 5222 results. Down converted signal 5222 is routed through an amplifier 5214 and a filter 5216, and a filtered signal 5224 results. In a preferred embodiment, filtered signal 5224 is at baseband, and a decoder 5218 may only be needed to convert digital to analog or to remove encryption before outputting the baseband information signal. This then is a universal frequency down conversion receiver operating in a direct down conversion mode, in that it receives the EM signal 5220 and down converts it to baseband signal 5226 without requiring an IF or a demodulator. In an alternate embodiment, the filtered signal 5224 may be at an "offset" frequency. That is, it is at an intermediate frequency, similar to that described above for the second IF signal in a typical superheterodyne receiver. In this case, the decoder

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5218 would be used to demodulate the filtered signal so that it could output a baseband signal 5226.

An exemplary transmitter using the present invention is shown in FIG. 53. In the FM and PM embodiments, an information signal 5302 modulates an oscillating signal 5306 which is routed to a pulse shaping circuit 5310 which outputs a string of pulses 5311. The string of pulses 5311 controls the opening and closing of the switch 5312. One terminal of switch 5312 is connected to ground 5314, and the second terminal of switch 5312 is connected through a resistor 5330 to a bias/reference signal 5308. In the FM and PM modes, bias/reference signal 5308 is preferably a non-varying signal, often referred to simply as the bias signal. In the AM mode, the oscillating signal 5306 is not modulated, and the bias/reference signal is a function of the information signal 5304. In one embodiment, information signal 5304 is combined with a bias voltage to generate the reference signal 5308. In an alternate embodiment, the information signal 5304 is used without being combined with a bias voltage. Typically, in the AM mode, this bias/reference signal is referred to as the reference signal to distinguish it from the bias signal used in the FM and PM modes. The output of switch 5312 is a harmonically rich signal 5316 which is routed to a "high Q" filter which removes the unwanted frequencies that exist as harmonic components of harmonically rich signal 5316. Desired frequency 5320 is amplified by amplifier module 5322 and routed to transmission module 5324 which outputs a transmission signal 5326. Transmission signal is output by antenna 5328 in this embodiment.

For the FM and PM modulation modes, FIGS. 54A, 54B, and 54C show the combination of the present invention of the transmitter and the universal frequency down-conversion receiver in the half-duplex mode according to an embodiment of the invention. That is, the transceiver can transmit and receive, but it cannot do both simultaneously. It uses a single antenna 5402, a single oscillator 5444/5454 (depending on whether the transmitter is in the FM or PM modulation mode), a single pulse shaper 5438, and a single switch 5420 to transmit and to receive. In the receive function, "Receiver/transmitter" (R/T) switches 5406, 5408, and 5446/5452 (FM or PM) would all be in the receive position, designated by (R). The antenna 5402 receives an EM signal 5404 and routes it through a capacitor 5407. In the FM modulation mode, oscillating signal 5436 is generated by a voltage controlled oscillator (VCO) 5444. Because the transceiver is performing the receive function, switch 5446 connects the input to the VCO 5444 to ground 5448. Thus, VCO 5444 will operate as if it were a simple oscillator. In the PM modulation mode, oscillating signal 5436 is generated by local oscillator 5454 which is routed through phase modulator 5456. Since the transceiver is performing the receive function, switch 5452 is connected to ground 5448, and there is no modulating input to phase modulator. Thus, local oscillator 5454 and phase modulator 5456 operate as if they were a simple oscillator. One skilled in the relevant art(s) will recognize based on the discussion contained herein that there are numerous embodiments wherein an oscillating signal 5436 can be generated to control the switch 5420.

Oscillating signal 5436 is shaped by pulse shaper 5438 to produce a string of pulses 5440. The string of pulses 5440 cause the switch 5420 to open and close. As a result of the switch opening and closing, a down converted signal 5409 is generated. The down converted signal 5409 is amplified and filtered to create a filtered signal 5413. In an embodiment, filtered signal 5413 is at baseband and, as a result of the down conversion, is demodulated. Thus, a decoder 5414 may not be required except to convert digital to analog or to decrypt the

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filtered signal **5413**. In an alternate embodiment, the filtered signal **5413** is at an "offset" frequency, so that the decoder **5414** is needed to demodulate the filtered signal and create a demodulated baseband signal.

When the transceiver is performing the transmit function, the R/T switches **5406**, **5408**, and **5446/5452** (FM or PM) are in the (T) position. In the FM modulation mode, an information signal **5450** is connected by switch **5446** to VCO **5444** to create a frequency modulated oscillating signal **5436**. In the PM modulation mode switch **5452** connects information signal **5450** to the phase modulator **5456** to create a phase modulated oscillating signal **5436**. Oscillation signal **5436** is routed through pulse shaper **5438** to create a string of pulses **5440** which in turn cause switch **5420** to open and close. One terminal of switch **5420** is connected to ground **5442** and the other is connected through switch R/T **5408** and resistor **5423** to a bias signal **5422**. The result is a harmonically rich signal **5424** which is routed to a "high Q" filter **5426** which removes the unwanted frequencies that exist as harmonic components of harmonically rich signal **5424**. Desired frequency **5428** is amplified by amplifier module **5430** and routed to transmission module **5432** which outputs a transmission signal **5434**. Again, because the transceiver is performing the transmit function, R/T switch **5406** connects the transmission signal to the antenna **5402**.

In the AM modulation mode, the transceiver operates in the half duplex mode as shown in FIG. **55**. The only distinction between this modulation mode and the FM and PM modulation modes described above, is that the oscillating signal **5436** is generated by a local oscillator **5502**, and the switch **5420** is connected through the R/T switch **5408** and resistor **5423** to a reference signal **5506**. Reference signal **5506** is generated when information signal **5450** and bias signal **5422** are combined by a summing module **5504**. It is well known to those skilled in the relevant art(s) that the information signal **5450** may be used as the reference signal **5506** without being combined with the bias signal **5422**, and may be connected directly (through resistor **5423** and R/T switch **5408**) to the switch **5420**.

Third Embodiment: The Transmitter of the Present Invention Being Used with a Universal Frequency Down Converter in a Full-Duplex Mode.

The full-duplex mode differs from the half-duplex mode in that the transceiver can transmit and receive simultaneously. Referring to FIG. **56**, to achieve this, the transceiver preferably uses a separate circuit for each function. A duplexer **5604** is used in the transceiver to permit the sharing of an antenna **5602** for both the transmit and receive functions.

The receiver function performs as follows. The antenna **5602** receives an EM signal **5606** and routes it through a capacitor **5607** to one terminal of a switch **5626**. The other terminal of switch **5626** is connected to ground **5628**, and the switch is driven as a result of a string of pulses **5624** created by local oscillator **5620** and pulse shaper **5622**. The opening and closing of switch **5626** generates a down converted signal **5614**. Down converted signal **5614** is routed through an amplifier **5608** and a filter **5610** to generate filtered signal **5616**. Filtered signal **5616** may be at baseband and be demodulated or it may be at an "offset" frequency. If filtered signal **5616** is at an offset frequency, decoder **5612** will demodulate it to create the demodulated baseband signal **5618**. In a preferred embodiment, however, the filtered signal **5616** will be a demodulated baseband signal, and decoder **5612** may not be required except to convert digital to analog or to decrypt filtered signal **5616**. This receiver portion of the transceiver can operate independently from the transmitter portion of the transceiver.

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The transmitter function is performed as follows. In the FM and PM modulation modes, an information signal **5648** modulates an oscillating signal **5630**. In the AM modulation mode, the oscillating signal **5630** is not modulated. The oscillating signal is shaped by pulse shaper **5632** and a string of pulses **5634** is created. This string of pulses **5634** causes a switch **5636** to open and close. One terminal of switch **5636** is connected to ground **5638**, and the other terminal is connected through a resistor **5647** to a bias/reference signal **5646**. In the FM and PM modulation modes, bias/reference signal **5646** is referred to as a bias signal **5646**, and it is substantially non-varying. In the AM modulation mode, an information signal **5650** may be combined with the bias signal to create what is referred to as the reference signal **5646**. The reference signal **5646** is a function of the information signal **5650**. It is well known to those skilled in the relevant art(s) that the information signal **5650** may be used as the bias/reference signal **5646** directly without being summed with a bias signal. A harmonically rich signal **5652** is generated and is filtered by a "high Q" filter **5640**, thereby producing a desired signal **5654**. The desired signal **5654** is amplified by amplifier **5642** and routed to transmission module **5644**. The output of transmission module **5644** is transmission signal **5656**. Transmission signal **5656** is routed to duplexer **5604** and then transmitted by antenna **5602**. This transmitter portion of the transceiver can operate independently from the receiver portion of the transceiver.

Thus, as described above, the transceiver embodiment the present invention as shown in FIG. **56** can perform full-duplex communications in all modulation modes.

#### Other Embodiments and Implementations

Other embodiments and implementations of the receiver/transmitter of the present invention would be apparent to one skilled in the relevant art(s) based on the discussion herein.

The embodiments and implementations described above are provided for purposes of illustration. These embodiments and implementations are not intended to limit the invention. Alternatives, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments and implementations fall within the scope and spirit of the present invention.

#### 6.3 Summary Description of Down-conversion Using a Universal Frequency Translation Module.

The following discussion describes down-converting using a Universal Frequency Translation Module. The down-conversion of an EM signal by aliasing the EM signal at an aliasing rate is fully described in co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," application Ser. No. 09/176,022, now issued as U.S. Pat. No. 6,061,551, the full disclosure of which is incorporated herein by reference. A relevant portion of the above mentioned patent application is summarized below to describe down-converting an input signal to produce a down-converted signal that exists at a lower frequency or a baseband signal.

FIG. **64A** illustrates an aliasing module **6400** for down-conversion using a universal frequency translation (UFT) module **6402** which down-converts an EM input signal **6404**. In particular embodiments, aliasing module **6400** includes a switch **6408** and a capacitor **6410**. The electronic alignment of the circuit components is flexible. That is, in one implementation, the switch **6408** is in series with input signal **6404** and capacitor **6410** is shunted to ground (although it may be other than ground in configurations such as differential mode). In a second implementation (see FIG. **64A-1**), the capacitor **6410** is in series with the input signal **6404** and the

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switch **6408** is shunted to ground (although it may be other than ground in configurations such as differential mode). Aliasing module **6400** with UFT module **6402** can be easily tailored to down-convert a wide variety of electromagnetic signals using aliasing frequencies that are well below the frequencies of the EM input signal **6404**.

In one implementation, aliasing module **6400** down-converts the input signal **6404** to an intermediate frequency (IF) signal. In another implementation, the aliasing module **6400** down-converts the input signal **6404** to a demodulated baseband signal. In yet another implementation, the input signal **6404** is a frequency modulated (FM) signal, and the aliasing module **6400** down-converts it to a non-FM signal, such as a phase modulated (PM) signal or an amplitude modulated (AM) signal. Each of the above implementations is described below.

In an embodiment, the control signal **6406** includes a train of pulses that repeat at an aliasing rate that is equal to, or less than, twice the frequency of the input signal **6404**. In this embodiment, the control signal **6406** is referred to herein as an aliasing signal because it is below the Nyquist rate for the frequency of the input signal **6404**. Preferably, the frequency of control signal **6406** is much less than the input signal **6404**.

The train of pulses **6418** as shown in FIG. **64D** controls the switch **6408** to alias the input signal **6404** with the control signal **6406** to generate a down-converted output signal **6412**. More specifically, in an embodiment, switch **6408** closes on a first edge of each pulse **6420** of FIG. **64D** and opens on a second edge of each pulse. When the switch **6408** is closed, the input signal **6404** is coupled to the capacitor **6410**, and charge is transferred from the input signal to the capacitor **6410**. The charge stored during successive pulses forms down-converted output signal **6412**.

Exemplary waveforms are shown in FIGS. **64B-64F**.

FIG. **64B** illustrates an analog amplitude modulated (AM) carrier signal **6414** that is an example of input signal **6404**. For illustrative purposes, in FIG. **64C**, an analog AM carrier signal portion **6416** illustrates a portion of the analog AM carrier signal **6414** on an expanded time scale. The analog AM carrier signal portion **6416** illustrates the analog AM carrier signal **6414** from time  $t_0$  to time  $t_1$ .

FIG. **64D** illustrates an exemplary aliasing signal **6418** that is an example of control signal **6406**. Aliasing signal **6418** is on approximately the same time scale as the analog AM carrier signal portion **6416**. In the example shown in FIG. **64D**, the aliasing signal **6418** includes a train of pulses **6420** having negligible apertures that tend towards zero (the invention is not limited to this embodiment, as discussed below). The pulse aperture may also be referred to as the pulse width as will be understood by those skilled in the art(s). The pulses **6420** repeat at an aliasing rate, or pulse repetition rate of aliasing signal **6418**. The aliasing rate is determined as described below, and further described in co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," application Ser. No. 09/176,022, now issued as U.S. Pat. No. 6,061,551.

As noted above, the train of pulses **6420** (i.e., control signal **6406**) control the switch **6408** to alias the analog AM carrier signal **6416** (i.e., input signal **6404**) at the aliasing rate of the aliasing signal **6418**. Specifically, in this embodiment, the switch **6408** closes on a first edge of each pulse and opens on a second edge of each pulse. When the switch **6408** is closed, input signal **6404** is coupled to the capacitor **6410**, and charge is transferred from the input signal **6404** to the capacitor **6410**. The charge transferred during a pulse is referred to herein as an under-sample. Exemplary under-samples **6422** form down-converted signal portion **6424** (FIG. **64E**) that

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corresponds to the analog AM carrier signal portion **6416** (FIG. **64C**) and the train of pulses **6420** (FIG. **64D**). The charge stored during successive under-samples of AM carrier signal **6414** form the down-converted signal **6424** (FIG. **64E**) that is an example of down-converted output signal **6412** (FIG. **64A**). In FIG. **64F** a demodulated baseband signal **6426** represents the demodulated baseband signal **6424** after filtering on a compressed time scale. As illustrated, down-converted signal **6426** has substantially the same "amplitude envelope" as AM carrier signal **6414**. Therefore, FIGS. **64B-64F** illustrate down-conversion of AM carrier signal **6414**.

The waveforms shown in FIGS. **64B-64F** are discussed herein for illustrative purposes only, and are not limiting. Additional exemplary time domain and frequency domain drawings, and exemplary methods and systems of the invention relating thereto, are disclosed in co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," application Ser. No. 09/176,022, now issued as U.S. Pat. No. 6,061,551.

The aliasing rate of control signal **6406** determines whether the input signal **6404** is down-converted to an IF signal, down-converted to a demodulated baseband signal, or down-converted from an FM signal to a PM or an AM signal. Generally, relationships between the input signal **6404**, the aliasing rate of the control signal **6406**, and the down-converted output signal **6412** are illustrated below:

$$(\text{Freq. of input signal } 6404) = n \cdot (\text{Freq. of control signal } 6406) \pm (\text{Freq. of Down-Converted Output Signal } 6412)$$

For the examples contained herein, only the "+" condition will be discussed. The value of  $n$  represents a harmonic or sub-harmonic of input signal **6404** (e.g.,  $n=0.5, 1, 2, 3, \dots$ ).

When the aliasing rate of control signal **6406** is off-set from the frequency of input signal **6404**, or off-set from a harmonic or sub-harmonic thereof, input signal **6404** is down-converted to an IF signal. This is because the under-sampling pulses occur at different phases of subsequent cycles of input signal **6404**. As a result, the under-samples form a lower frequency oscillating pattern. If the input signal **6404** includes lower frequency changes, such as amplitude, frequency, phase, etc., or any combination thereof, the charge stored during associated under-samples reflects the lower frequency changes, resulting in similar changes on the down-converted IF signal. For example, to down-convert a 901 MHz input signal to a 1 MHz IF signal, the frequency of the control signal **6406** would be calculated as follows:

$$(\text{Freq}_{\text{input}} - \text{Freq}_{\text{IF}}) / n = \text{Freq}_{\text{control}} (901 \text{ MHz} - 1 \text{ MHz}) / n = 900 / n$$

For  $n=0.5, 1, 2, 3, 4, \dots$ , the frequency of the control signal **6406** would be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc.

Exemplary time domain and frequency domain drawings, illustrating down-conversion of analog and digital AM, PM and FM signals to IF signal, and exemplary methods and systems thereof, are disclosed in co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," Application No. 09/176,022, now issued as U.S. Pat. No. 6,061,551.

Alternatively, when the aliasing rate of the control signal **6406** is substantially equal to the frequency of the input signal **6404**, or substantially equal to a harmonic or sub-harmonic thereof, input signal **6404** is directly down-converted to a demodulated baseband signal. This is because, without modulation, the under-sampling pulses occur at the same point of subsequent cycles of the input signal **6404**. As a result, the under-samples form a constant output baseband

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signal. If the input signal **6404** includes lower frequency changes, such as amplitude, frequency, phase, etc., or any combination thereof, the charge stored during associated under-samples reflects the lower frequency changes, resulting in similar changes on the demodulated baseband signal. For example, to directly down-convert a 900 MHz input signal to a demodulated baseband signal (i.e., zero IF), the frequency of the control signal **6406** would be calculated as follows:

$$(Freq_{input} - Freq_{IF})/n = Freq_{control} (900 \text{ MHz} - 0 \text{ MHz}) / n = 900 \text{ MHz} / n$$

For  $n=0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal **6406** should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc.

Exemplary time domain and frequency domain drawings, illustrating direct down-conversion of analog and digital AM and PM signals to demodulated baseband signals, and exemplary methods and systems thereof, are disclosed in the co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," application Ser. No. 09/176,022, now issued as U.S. Pat. No. 6,061,551.

Alternatively, to down-convert an input FM signal to a non-FM signal, a frequency within the FM bandwidth must be down-converted to baseband (i.e., zero IF). As an example, to down-convert a frequency shift keying (FSK) signal (a sub-set of FM) to a phase shift keying (PSK) signal (a subset of PM), the mid-point between a lower frequency  $F_1$  and an upper frequency  $F_2$  (that is,  $[(F_1 + F_2)/2]$ ) of the FSK signal is down-converted to zero IF. For example, to down-convert an FSK signal having  $F_1$  equal to 899 MHz and  $F_2$  equal to 901 MHz, to a PSK signal, the aliasing rate of the control signal **6406** would be calculated as follows:

$$\begin{aligned} \text{Frequency of the input} &= (F_1 + F_2) \div 2 \\ &= (899 \text{ MHz} + 901 \text{ MHz}) \div 2 \\ &= 900 \text{ MHz} \end{aligned}$$

Frequency of the down-converted signal = 0 (i.e., baseband)

$$\begin{aligned} (Freq_{input} - Freq_{IF})/n &= Freq_{control} \\ (900 \text{ MHz} - 0 \text{ MHz})/n &= 900 \text{ MHz}/n \end{aligned}$$

For  $n=0.5, 1, 2, 3$ , etc., the frequency of the control signal **6406** should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc. The frequency of the down-converted PSK signal is substantially equal to one half the difference between the lower frequency  $F_1$  and the upper frequency  $F_2$ .

As another example, to down-convert a FSK signal to an amplitude shift keying (ASK) signal (a subset of AM), either the lower frequency  $F_1$  or the upper frequency  $F_2$  of the FSK signal is down-converted to zero IF. For example, to down-convert an FSK signal having  $F_1$  equal to 900 MHz and  $F_2$  equal to 901 MHz, to an ASK signal, the aliasing rate of the control signal **6406** should be substantially equal to:

$$(900 \text{ MHz} - 0 \text{ MHz})/n = 900 \text{ MHz}/n, \text{ or}$$

$$(901 \text{ MHz} - 0 \text{ MHz})/n = 901 \text{ MHz}/n.$$

For the former case of 900 MHz/ $n$ , and for  $n=0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal **6406** should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc. For the latter case of 901 MHz/ $n$ , and for  $n=0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal **6406** should

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be substantially equal to 1.802 GHz, 901 MHz, 450.5 MHz, 300.333 MHz, 225.25 MHz, etc. The frequency of the down-converted AM signal is substantially equal to the difference between the lower frequency  $F_1$  and the upper frequency  $F_2$  (i.e., 1 MHz).

Exemplary time domain and frequency domain drawings, illustrating down-conversion of FM signals to non-FM signals, and exemplary methods and systems thereof, are disclosed in the co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," Application No. (09/176,022, now issued as U.S. Pat. No. 6,061,551).

In an embodiment, the pulses of the control signal **6406** have negligible apertures that tend towards zero. This makes the UFT module **6402** a high input impedance device. This configuration is useful for situations where minimal disturbance of the input signal may be desired.

In another embodiment, the pulses of the control signal **6406** have non-negligible apertures that tend away from zero. This makes the UFT module **6402** a lower input impedance device. This allows the lower input impedance of the UFT module **6402** to be substantially matched with a source impedance of the input signal **6404**. This also improves the energy transfer from the input signal **6404** to the down-converted output signal **6412**, and hence the efficiency and signal to noise (s/n) ratio of UFT module **6402**.

Exemplary systems and methods for generating and optimizing the control signal **6406**, and for otherwise improving energy transfer and s/n ratio, are disclosed in the co-pending U.S. patent application entitled "Method and System for Down-converting an Electromagnetic Signal," application Ser. No. 09/176,022, now issued as U.S. Pat. No. 6,061,551. Designing a Transmitter According to an Embodiment of the Present Invention.

This section (including its subsections) provides a high-level description of an exemplary process to be used to design a transmitter according to an embodiment of the present invention. The techniques described herein are also applicable to designing a frequency up-converter for any application, and for designing the applications themselves. The descriptions are contained herein for illustrative purposes and are not limiting. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention, and the invention is intended and adapted to include such alternative.

The discussion herein describes an exemplary process to be used to design a transmitter according to an embodiment of the present invention. An exemplary circuit for a transmitter of the present invention operating in the FM embodiment is shown in FIG. 57A. Likewise, FIG. 57B illustrates the transmitter of the present invention operating in the PM embodiment, and FIG. 57C shows the transmitter of the present invention operating in the AM embodiment. These circuits have been shown in previous figures, but are presented here to facilitate the discussion of the design. As the "I/Q" embodiment of the present invention is a subset of the PM embodiment, it will not be shown in a separate figure here, since the design approach will be very similar to that for the PM embodiment.

Depending on the application and on the implementation, some of the design considerations may not apply. For example, and without limitation, in some cases it may not be necessary to optimize the pulse width or to include an amplifier.

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Frequency of the Transmission Signal.

The first step in the design process is to determine the frequency of the desired transmission signal **5714**. This is typically determined by the application for which the transmitter is to be used. The present invention is for a transmitter that can be used for all frequencies within the electromagnetic (EM) spectrum. For the examples herein, the explanation will focus on the use of the transmitter in the 900 MHz to 950 MHz range. Those skilled in the relevant art(s) will recognize that the analysis contained herein may be used for any frequency or frequency range.

Characteristics of the Transmission Signal.

Once the frequency of the desired transmission signal **5714** is known, the characteristics of the signal must be determined. These characteristics include, but are not limited to, whether the transmitter will operate at a fixed frequency or over a range of frequencies, and if it is to operate over a range of frequencies, whether those frequencies are continuous or are divided into discrete "channels." If the frequency range is divided into discrete channels, the spacing between the channels must be ascertained. As an example, cordless phones operating in this frequency range may operate on discrete channels that are 50 KHz apart. That is, if the cordless phones operate in the 905 MHz to 915 MHz range (inclusive), the channels could be found at 905.000, 905.050, 905.100, 914.900, 914.950, and 915.000.

Modulation Scheme.

Another characteristic that must be ascertained is the desired modulation scheme that is to be used. As described above in sections 2.1-2.2.4, above, these modulation schemes include FM, PM, AM, etc., and any combination or subset thereof, specifically including the widely used "I/Q" subset of PM. Just as the frequency of the desired transmission signal **5714** is typically determined by the intended application, so too is the modulation scheme.

Characteristics of the Information Signal.

The characteristics of an information signal **5702** are also factors in the design of the transmitter circuit. Specifically, the bandwidth of the information signal **5702** defines the minimum frequency for an oscillating signal **5704**, **5738**, **5744** (for the FM, PM, and AM modes, respectively).

Characteristics of the Oscillating Signal.

The desired frequency of the oscillating signal **5704**, **5738**, **5744** is also a function of the frequency and characteristics of the desired transmission signal **5714**. Also, the frequency and characteristics of the desired transmission signal **5714** are factors in determining the pulse width of the pulses in a string of pulses **5706**. Note that the frequency of the oscillating signal **5704**, **5738**, **5744** is substantially the same as the frequency of the string of pulses **5706**. (An exception, which is discussed below, is when a pulse shaping circuit **5722** increases the frequency of the oscillating signal **5704**, **5738**, **5744** in a manner similar to that described above in section 4.3.2.) Note also that the frequency and pulse width of the string of pulses **5706** is substantially the same as the frequency and pulse width of a harmonically rich signal **5708**.

Frequency of the Oscillating Signal.

The frequency of the oscillating signal **5704**, **5738**, **5744** must be a subharmonic of the frequency of the desired transmission signal **5714**. A subharmonic is the quotient obtained by dividing the fundamental frequency, in this case the frequency of the desired transmission signal **5714**, by an integer. When describing the frequency of certain signals, reference is often made herein to a specific value. It is understood by those skilled in the relevant art(s) that this reference is to the nominal center frequency of the signal, and that the actual signal may vary in frequency above and below this nominal center

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frequency based on the desired modulation technique being used in the circuit. As an example to be used herein, if the frequency of the desired transmission signal is 910 MHz, and it is to be used in an FM mode where, for example, the frequency range of the modulation is 40 KHz, the actual frequency of the signal will vary  $\pm 20$  KHz around the nominal center frequency as a function of the information being transmitted. That is, the frequency of the desired transmission signal will actually range between 909.980 MHz and 910.020 MHz.

The first ten subharmonics of a 910.000 MHz signal are given below.

harmonic	frequency
1 <sup>st</sup>	910.000 MHz
2 <sup>nd</sup>	455.000
3 <sup>rd</sup>	303.333 ...
4 <sup>th</sup>	227.500
5 <sup>th</sup>	182.000
6 <sup>th</sup>	151.666 ...
7 <sup>th</sup>	130.000
8 <sup>th</sup>	113.750
9 <sup>th</sup>	101.111 ...
10 <sup>th</sup>	91.000

The oscillating signal **5704**, **5738**, **5744** can be at any one of these frequencies or, if desired, at a lower subharmonic. For discussion herein, the 9<sup>th</sup> subharmonic will be chosen. Those skilled in the relevant art(s) will understand that the analysis herein applies regardless of which harmonic is chosen. Thus the nominal center frequency of the oscillating signal **5704**, **5738**, **5744** will be 101.1111 MHz. Recalling that in the FM mode, the frequency of the desired transmission signal **5714** is actually 910.000 MHz  $\pm 0.020$  MHz, it can be shown that the frequency of the oscillating signal **5704** will vary  $\pm 0.00222$  MHz (i.e., from 101.10889 MHz to 101.11333 MHz). The frequency and frequency sensitivity of the oscillating signal **5704** will drive the selection or design of the voltage controlled oscillator (VCO) **5720**.

Another frequency consideration is the overall frequency range of the desired transmission signal. That is, if the transmitter is to be used in the cordless phone of the above example and will transmit on all channels between 905 MHz and 915 MHz, the VCO **5720** (for the FM mode) or the local oscillator (LO) **5734** (for the PM and AM modes) will be required to generate oscillating frequencies **5704**, **5738**, **5744** that range from 100.5556 MHz to 101.6667 MHz. (That is, the 9<sup>th</sup> subharmonic of 910 MHz  $\pm 5$  MHz). In some applications, such as the cellular phone, the frequencies will change automatically, based on the protocols of the overall cellular system (e.g., moving from one cell to an adjacent cell). In other applications, such as a police radio, the frequencies will change based on the user changing channels.

In some applications, different models of the same transmitter will transmit signals at different frequencies, but each model will, itself, only transmit a single frequency. A possible example of this might be remote controlled toy cars, where each toy car operates on its own frequency, but, in order for several toy cars to operate in the same area, there are several frequencies at which they could operate. Thus, the design of the VCO **5720** or LO **5734** will be such that it is able to be tuned to a set frequency when the circuit is fabricated, but the user will typically not be able to adjust the frequency.

It is well known to those skilled in the relevant art(s) that several of the criteria to be considered in the selection or design of an oscillator (VCO **5720** or LO **5734**) include, but

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are not limited to, the nominal center frequency of the desired transmission signal **5714**, the frequency sensitivity caused by the desired modulation scheme, the range of all possible frequencies for the desired transmission signal **5714**, and the timing requirements for each specific application. Another important criterion is the determination of the subharmonic to be used, but unlike the criteria listed above which are dependent on the desired application, there is some flexibility in the selection of the subharmonic.

Pulse Width of the String of Pulses.

Once the frequency of the oscillating signal **5704**, **5738**, **5744** has been selected, the pulse width of the pulses in the stream of pulses **5706** must be determined. (See sections 4-4.3.4, above, for a discussion of harmonic enhancement and the impact the pulse-width-to-period ratio has on the relative amplitudes of the harmonics in a harmonically rich signal **5708**.) In the example used above, the 9<sup>th</sup> subharmonic was selected as the frequency of the oscillating signal **5704**, **5738**, **5744**. In other words, the frequency of the desired transmission signal will be the 9<sup>th</sup> harmonic of the oscillating signal **5704**, **5738**, **5744**. One approach in selecting the pulse width might be to focus entirely on the frequency of the oscillating signal **5704**, **5738**, **5744** and select a pulse width and observe its operation in the circuit. For the case where the harmonically rich signal **5708** has a unity amplitude, and the pulse-width-to-period ratio is 0.1, the amplitude of the 9<sup>th</sup> harmonic will be 0.0219. Looking again at Table **6000** and FIG. **58** it can be seen that the amplitude of the 9<sup>th</sup> harmonic is higher than that of the 10<sup>th</sup> harmonic (which is zero) but is less than half the amplitude of the 8<sup>th</sup> harmonic. Because the 9<sup>th</sup> harmonic does have an amplitude, this pulse-width-to-period ratio could be used with proper filtering. Typically, a different ratio might be selected to try and find a ratio that would provide a higher amplitude.

Looking at Eq. 1 in section 4.1.1, it is seen that the relative amplitude of any harmonic is a function of the number of the harmonic and the pulse-width-to-period ratio of the underlying waveform. Applying calculus of variations to the equation, the pulse-width-to-period ratio that yields the highest amplitude harmonic for any given harmonic can be determined.

From Eq. 1, where  $A_n$  is the amplitude of the  $n^{\text{th}}$  harmonic,

$$A_n = [A_{\text{pulse}}] [(2/\pi)/n] \sin \{n\pi(\tau/T)\} \quad \text{Eq. 2}$$

If the amplitude of the pulse,  $A_{\text{pulse}}$ , is set to unity (i.e., equal to 1), the equation becomes

$$A_n = [2/(n\pi)] \sin [n\pi(\tau/T)] \quad \text{Eq. 3}$$

From this equation, it can be seen that for any value of  $n$  (the harmonic) the amplitude of that harmonic,  $A_n$ , is a function of the pulse-width-to-period ratio,  $\tau/T$ . To determine the highest value of  $A_n$  for a given value of  $n$ , the first derivative of  $A_n$  with respect to  $\tau/T$  is taken. This gives the following equations.

$$\delta(A_n)/\delta(\tau/T) = \delta\{[2/(n\pi)]\sin[n\pi(\tau/T)]\}/\delta(\tau/T) \quad \text{Eq. 4}$$

$$= [2/(n\pi)]\delta\{\sin[n\pi(\tau/T)]\}/\delta(\tau/T) \quad \text{Eq. 5}$$

$$= [2/(n\pi)]\cos[n\pi(\tau/T)] \quad \text{Eq. 6}$$

From calculus of variations, it is known that when the first derivative is set equal to zero, the value of the variable that will yield a relative maximum (or minimum) can be determined.

$$\delta(A_n)/\delta(\tau/T)=0 \quad \text{Eq. 7}$$

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$$[2/(n\pi)] \cos [n\pi(\tau/T)]=0 \quad \text{Eq. 8}$$

$$\cos [n\pi(\tau/T)]=0 \quad \text{Eq. 9}$$

From trigonometry, it is known that for Eq. 9 to be true,

$$n\pi(\tau/T)=\pi/2(\text{or } 3\pi/2, 5\pi/2, \text{etc.}) \quad \text{Eq. 10}$$

$$\tau/T=(\pi/2)/(n\pi) \quad \text{Eq. 11}$$

$$\tau/T=1/(2n)(\text{or } 3/(2n), 5/(2n), \text{etc.}) \quad \text{Eq. 12}$$

The above derivation is well known to those skilled in the relevant art(s). From Eq. 12, it can be seen that if the pulse-width-to-period ratio is equal to  $1/(2n)$ , the amplitude of the harmonic should be substantially optimum. For the case of the 9<sup>th</sup> harmonic, Eq. 12 will yield a pulse-width-to-period ratio of  $1/(2 \cdot 9)$  or 0.0556. For the amplitude of this 9<sup>th</sup> harmonic, Table **6100** of FIG. **61** shows that it is 0.0796. This is an improvement over the previous amplitude for a pulse-width-to-period ratio of 0.1. Table **6100** also shows that the 9<sup>th</sup> harmonic for this pulse-width-to-period ratio has the highest amplitude of any 9<sup>th</sup> harmonic, which bears out the derivation above. The frequency spectrum for a pulse-width-to-period ratio of 0.0556 is shown in FIG. **59**. (Note that other pulse-width-to-period ratios of  $3/(2n)$ ,  $5/(2n)$ , etc., will have amplitudes that are equal to but not larger than this one.)

This is one approach to determining the desired pulse-width-to-period ratio. Those skilled in the relevant art(s) will understand that other techniques may also be used to select a pulse-width-to-period ratio.

Design of the Pulse Shaping Circuit.

Once the determination has been made as to the desired frequency of the oscillating signal **5704**, **5738**, **5744** and of the pulse width, the pulse shaping circuit **5722** can be designed. Looking back to sections 4-4.3.4 it can be seen that the pulse shaping circuit **5722** can not only produce a pulse of a desired pulse width, but it can also cause the frequency of the string of pulses **5706** to be higher than the frequency of the oscillating signal **5704**, **5738**, **5744**. Recall that the pulse-width-to-period ratio applies to the pulse-width-to-period ratio of the harmonically rich signal **5708** and not to the pulse-width-to-period ratio of the oscillating signal **5704**, **5738**, **5744**, and that the frequency and pulse width of the harmonically rich signal **5708** mirrors the frequency and pulse width of the string of pulses **5706**. Thus, if in the selection of the VCO **5720** or LO **5734** it was desired to choose an oscillator that is lower than that required for the selected harmonic, the pulse shaping circuit **5733** can be used to increase the frequency. Going back to the previous example, the frequency of the oscillating signal **5704**, **5738**, **5744** could be 50.5556 MHz rather than 101.1111 MHz if the pulse shaping circuit **5722** was designed such as discussed in sections 4.2.2-4.2.2.2 (shown in FIGS. **40A-40D**) not only to shape the pulse, but also to double the frequency. While that discussion was specifically for a square wave input, those skilled in the relevant art(s) will understand that similar techniques will apply to non-rectangular waveforms (e.g., a sinusoidal wave). This use of the pulse shaping circuit to double the frequency has a possible advantage in that it allows the design and selection of an oscillator (VCO **5720** of LO **5734**) with a lower frequency, if that is a consideration.

It should also be understood that the pulse shaping circuit **5722** is not always required. If the design or selection of the VCO **5720** or LO **5734** was such that the oscillating signal **5704**, **5738**, **5744** was a substantially rectangular wave, and that substantially rectangular wave had a pulse-width-to-period ratio that was adequate, the pulse shaping circuit **5722** could be eliminated.

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Selection of the Switch.

The selection of a switch **5724** can now be made. The switch **5724** is shown in the examples of FIGS. **57A**, **57B**, and **57C** as a GaAsFET. However, it may be any switching device of any technology that can open and close “crisply” enough to accommodate the frequency and pulse width of the string of pulses **5706**.

Design of the Filter.

The design of the filter **5726** is determined by the frequency and frequency range of the desired transmission signal **5714**. As discussed above in sections 3.3.9-3.3.9.2, the term “Q” is used to describe the ratio of the center frequency of the output of the filter to the bandwidth of the “3 dB down” point. The trade offs that were made in the selection of the subharmonic to be used is a factor in designing the filter. That is, if, as an excursion to the example given above, the frequency of the desired transmission signal were again 910 MHz, but the desired subharmonic were the 50<sup>th</sup> subharmonic, then the frequency of that 50<sup>th</sup> subharmonic would be 18.2000 MHz. This means that the frequencies seen by the filter will be 18.200 MHz apart. Thus, the “Q” will need to be high enough to avoid allowing information from the adjacent frequencies being passed through. The other consideration for the “Q” of the filter is that it must not be so tight that it does not permit the usage of the entire range of desired frequencies.

Selection of an Amplifier.

An amplifier module **5728** will be needed if the signal is not large enough to be transmitted or if it is needed for some downstream application. This can occur because the amplitude of the resultant harmonic is too small. It may also occur if the filter **5726** has attenuated the signal.

Design of the Transmission Module.

A transmission module **5730**, which is optional, ensures that the output of the filter **5726** and the amplifier module **5728** is able to be transmitted. In the implementation wherein the transmitter is used to broadcast EM signals over the air, the transmission module matches the impedance of the output of the amplifier module **5728** and the input of an antenna **5732**. This technique is well known to those skilled in the relevant art(s). If the signal is to be transmitted over a point-to-point line such as a telephone line (or a fiber optic cable) the transmission module **5730** may be a line driver (or an electrical-to-optical converter for fiber optic implementation).

What is claimed is:

1. A frequency conversion module, comprising:
  - a first switch configured to up-convert a signal based on a control signal and a bias signal, wherein said signal are routed to said frequency conversion module via a second switch, and wherein said signal is transmitted by an antenna connected to a third switch.
2. The frequency conversion module of claim 1, wherein the first switch and the second switch are coupled to a transmission path comprising a filter, an amplifier, and a transmission module and wherein the transmission path is also coupled to a combining module, said combining module being configured to receive the bias signal and an information signal and to output a reference signal.
3. The frequency conversion module of claim 2, wherein, during a transmission of the signal, the first switch couples the antenna to the transmission path and the second switch couples the transmission path to the frequency conversion module.

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4. The frequency conversion module of claim 2, wherein the frequency conversion module is configured to receive the reference signal, via the second switch, during a transmission of the signal.

5. The frequency conversion module of claim 1, wherein, the frequency conversion module further comprises:

- a signal generator configured to generate the first control signal, the first control signal having a train of pulses that repeat at an aliasing rate substantially equal to, or less than, a frequency of the first signal.

6. The frequency conversion module of claim 1, further comprising:

- a pulse shaper; and
- an oscillating signal generator.

7. The frequency conversion module of claim 6, wherein the oscillating signal generator comprises a voltage controlled oscillator configured to generate an oscillating signal.

8. The frequency conversion module of claim 7, wherein the pulse shaper is configured to generate a string of pulses based on the oscillating signal.

9. The frequency conversion module of claim 8, wherein the first switch opens and closes based on the string of pulses.

10. The frequency conversion module of claim 8, wherein, during a transmission of the signal, the string of pulses is based on a frequency modulated oscillating signal.

11. The frequency conversion module of claim 8, wherein, during a transmission of the second signal, the string of pulses is based on a phase modulated oscillating signal.

12. A method for frequency conversion, comprising:

- up-converting a signal based on a control signal and a bias signal using a frequency conversion module, wherein the signal is routed to an antenna via a first switch, wherein the signal is routed to the frequency conversion module via a second switch, and wherein the frequency conversion module comprises a third switch and is configured to up-convert the signal using the third switch.

13. The method of claim 12, wherein, during a transmission of the signal, the signal is routed to the frequency conversion module by closing the first switch to couple the antenna to a transmission path and coupling the frequency conversion module to the transmission path with the second switch.

14. the method of claim 13, wherein the transmission path further comprises a filter, an amplifier, and a transmission module.

15. The method of claim 13, wherein the frequency conversion module further comprises:

- a combining module coupled to the transmission path, wherein the combining module is configured to receive a the bias signal and an information signal and to output a reference signal.

16. The method of claim 13 further comprising receiving a reference signal via the second switch a transmission of the signal.

17. The frequency converter of claim 12, wherein the frequency conversion module comprises a pulse shaper and an oscillating signal generator.

18. The frequency converter of claim 17, wherein the oscillating signal generator comprises a voltage controlled oscillator configured to generate an oscillating signal.

19. The frequency converter of claim 18, wherein the pulse shaper is configured to generate a string of pulses based on the oscillating signal.

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20. The frequency converter of claim 19, wherein the third switch opens and closes based on the string of pulses.

21. The frequency converter of claim 19, wherein, during a transmission of the signal, the string of pulses is based on a

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frequency modulated oscillating signal or a phase modulated oscillating signal.

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